STATUS OF CERES CLOUD PRODUCTS

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CERES Cloud Products

Provide consistent dataset from *TRMM, Terra, & Aqua* to

- **Relate cloud properties to the radiation budget**

- **Develop new bidirectional reflectance models for interpreting broadband radiance measurements**

- **Derive surface and atmospheric radiation budgets & the top-of-atmosphere ERB**

- **Provide data to initialize & validate climate & weather prediction models**

CERES Matched Cloud-Radiation Data

Broadband Radiances:

FOV = 10 - 20 km

Cloud Properties:

FOV = 2 km

Convolved in 2 layers (max)

Clear radiances saved

This is an SSF!

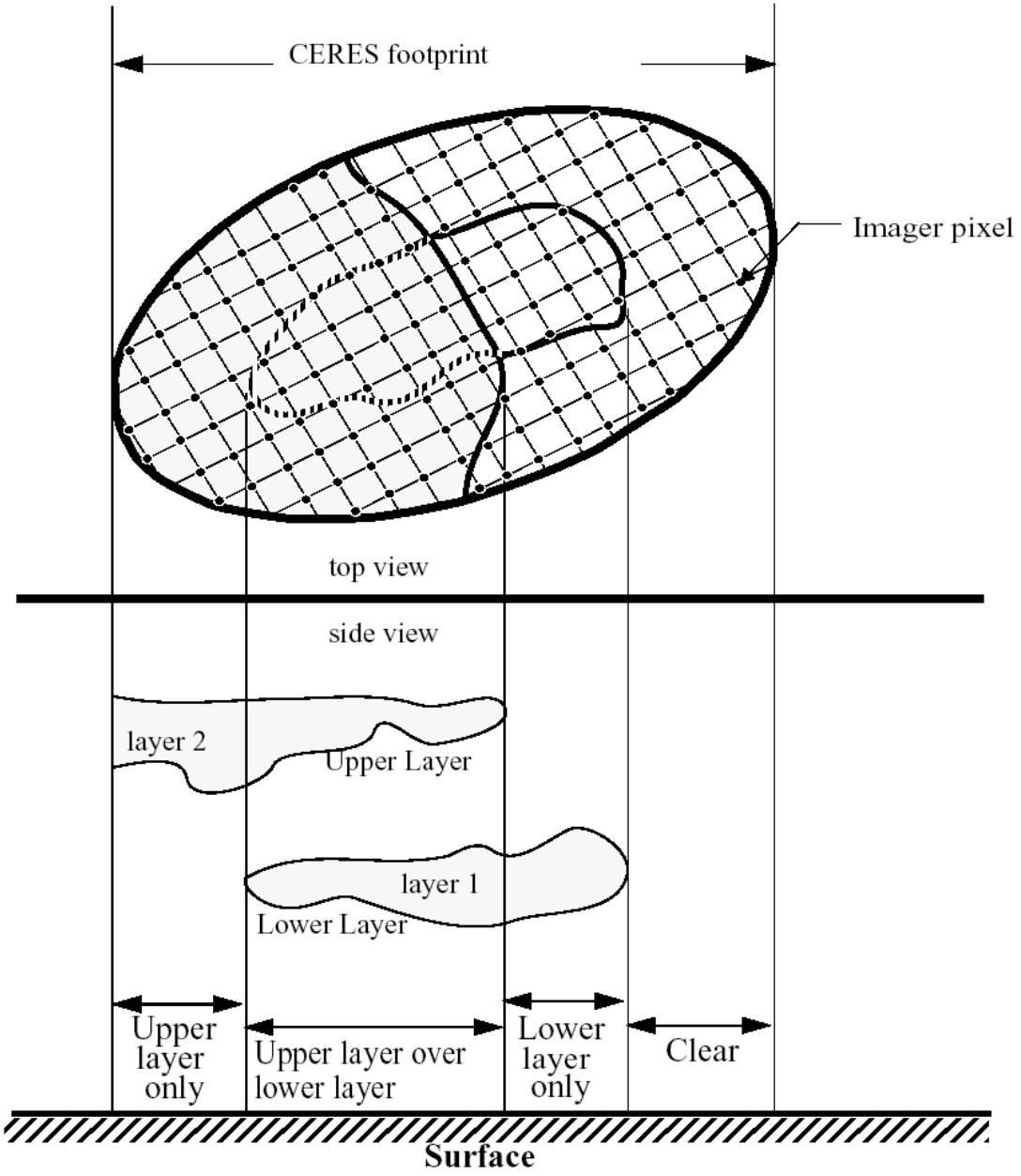


Figure 4-10. CERES Clear/layer/overlap illustration

CERES CLOUD PROPERTIES

1 SSF PIXEL w/CERES FLUXES
(SSF = Single Scanner Footprint)

AMOUNT	F
EFFECTIVE RADIATING TEMP	Tc
EFFECTIVE HEIGHT, PRESSURE	Zc, pc
TOP PRESSURE, HEIGHT	p_t, z_t
THICKNESS (base height)	h
EMISSIVITY	ε
PHASE (0 - 2)	P
WATER DROPLET EFFECTIVE RADIUS	re
OPTICAL DEPTH	τ
LIQUID WATER PATH	LWP
ICE EFFECTIVE DIAMETER	De
ICE WATER PATH	IWP

CALIBRATION

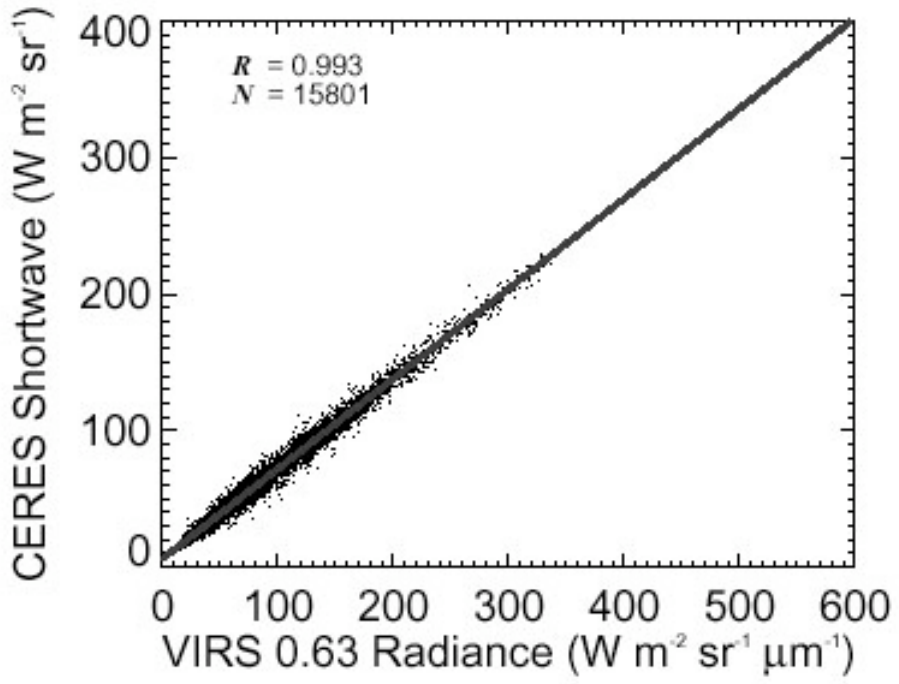
- **Extensive ongoing intercalibration effort**
  - **intercalibrate VIRS & MODIS; *Terra* & *Aqua* MODIS**
  - **determine stability by comparing imagers to CERES**
  - **examine all channels of interest (0.6, 0.86, 1.6, 3.7-3.9, 10.8, 12 *μ*m)**

    theoretically account for expected inter-satellite spectral differences
  - use statistics to reduce noise and angular/time matching errors

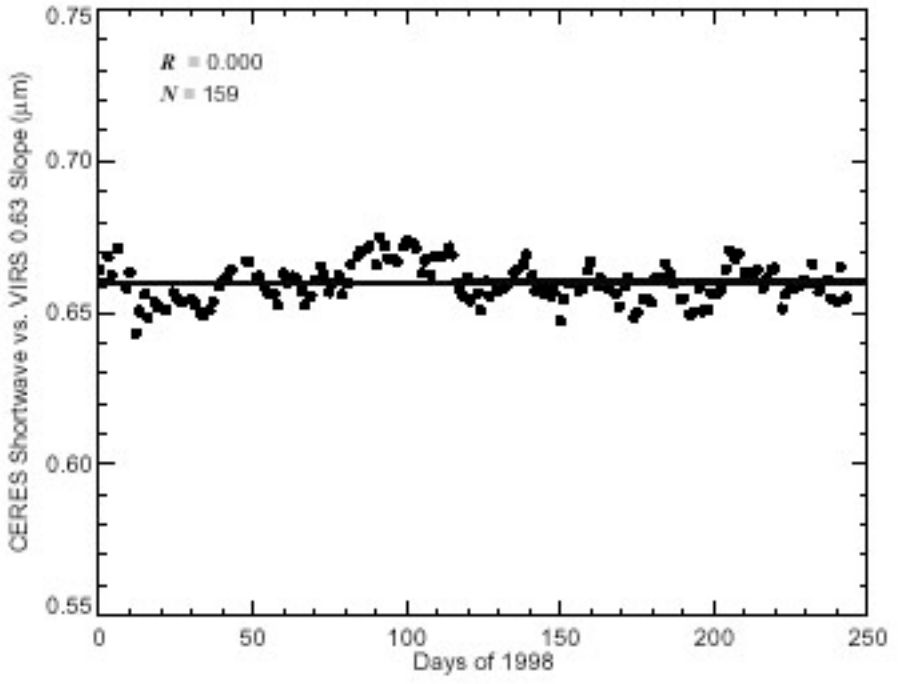
- **Intercalibrate other satellites for CERES & other projects**
  - link all considered satellites to references (VIRS or MODIS)
  - *GOES*-7, 8, 9, 10, 11, 12 (1993 - present)
  - AVHRR: *NOAA*-9,10, 11, 12, 14, 15, 16, 17 (1985 - present)
  - *GMS*-5, *Meteosat*-7 & **SEVIRI on *Meteosat-8***

USE CERES BROADBAND TO MONITOR TRENDS IN IMAGER CHANNELS

Compute slope for each day

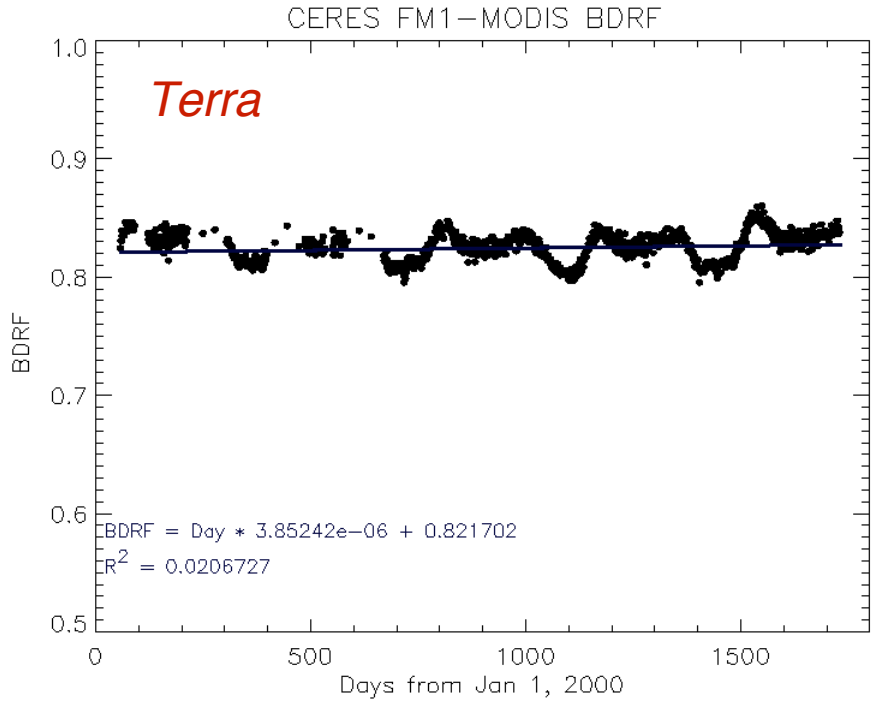


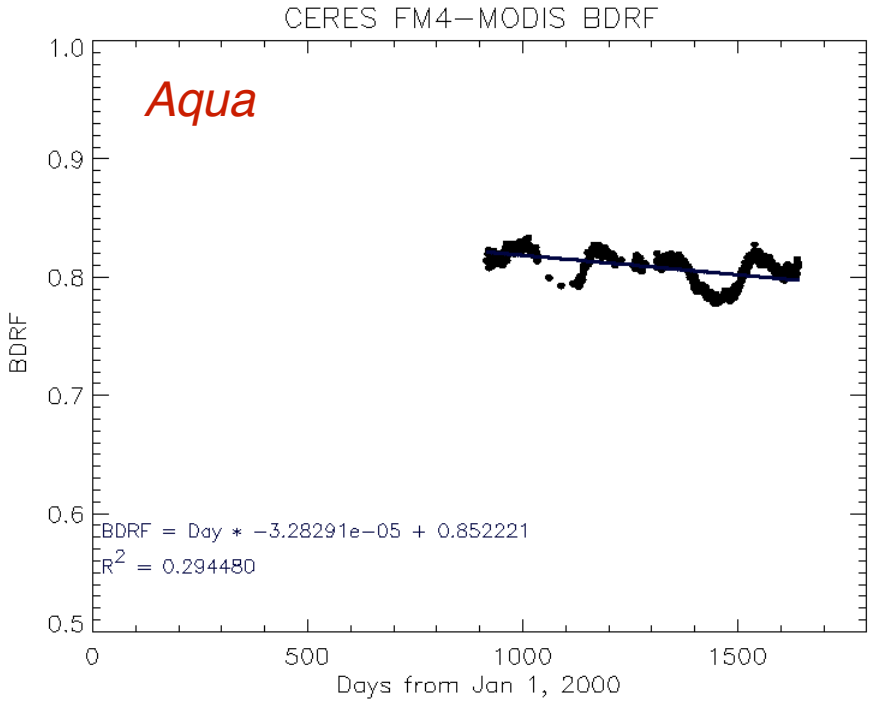
Monitor slope variation



INTERCALIBRATIONS
Comparison of CERES SW and *Aqua* MODIS
0.635 μm, July 2002 - July 2004

Ratio of radiances: SW / 0.64 μm



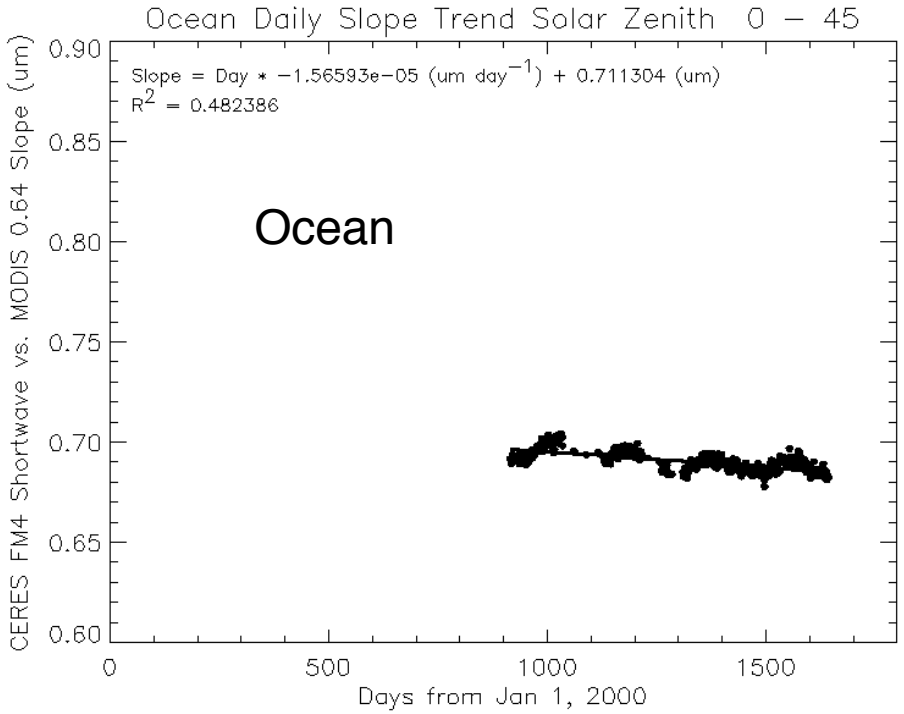


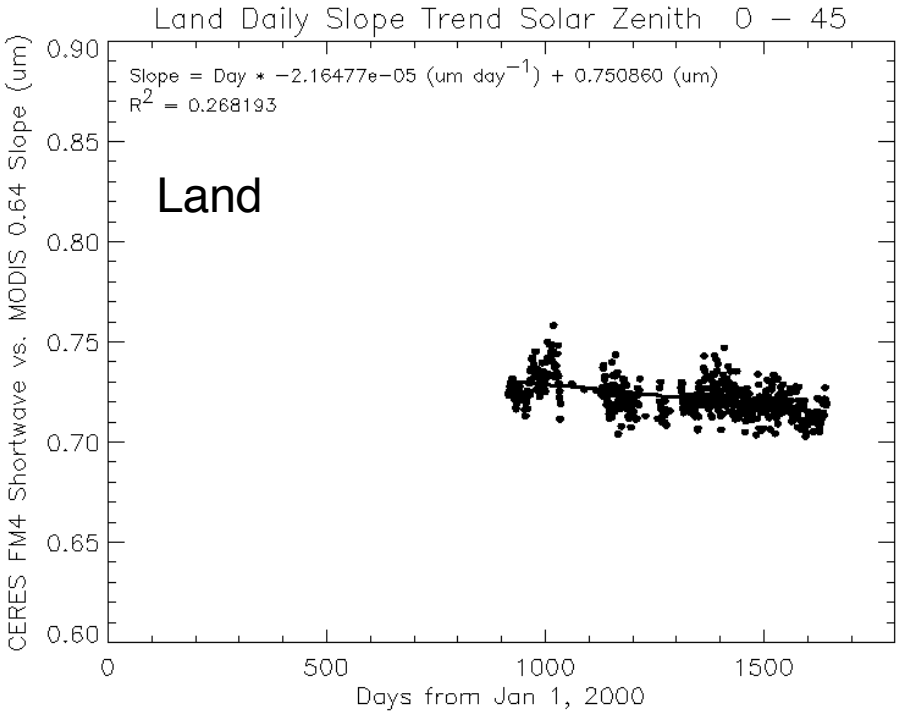
No trend for *Terra*; apparent trend for *Aqua*

Terra & Aqua MODIS have no trends relative to each other

***Terra* darker than *Aqua* by 1.2% at start of 2003**

Trend lines of VIS vs SW Regressions, *Aqua*
July 2002 - July 2004



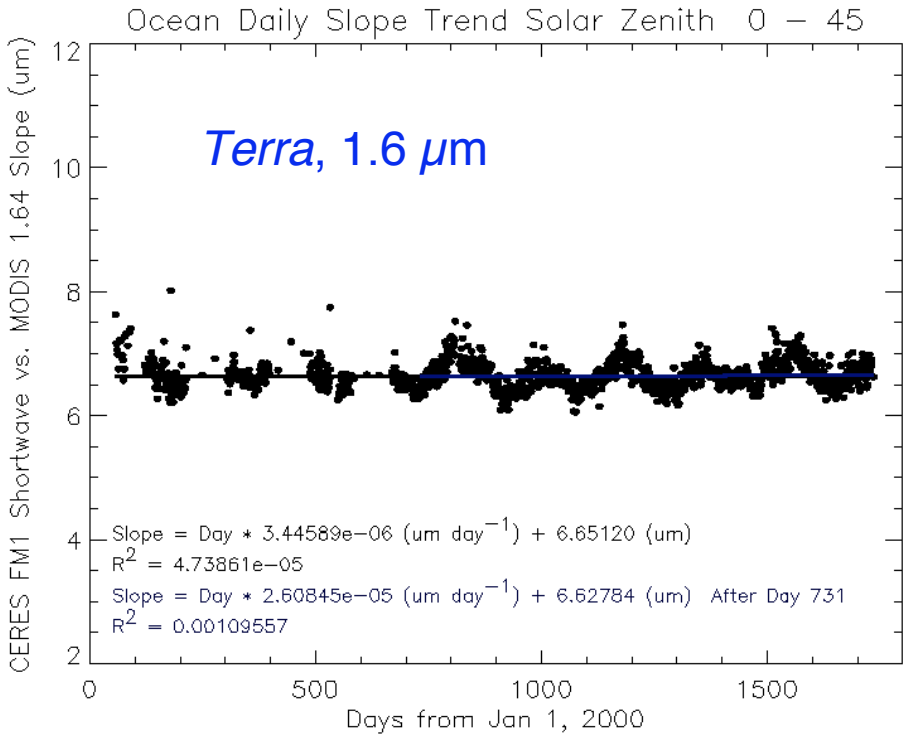


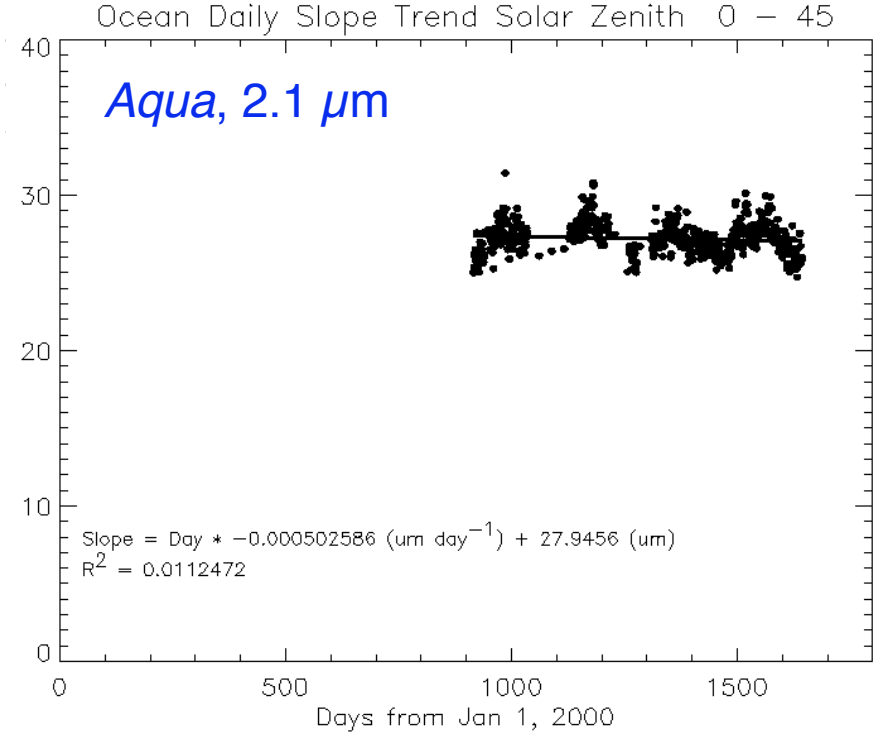
FM 1: => < 0.2%/yr increase

FM 4: VIS vs SW BRDF => 1.2%/ yr decrease in ratio

VIS vs SW => 0.75%, 0.79 (CERES darkening)

Comparison of CERES SW and MODIS Near-IR Channels, 2000 - 2004

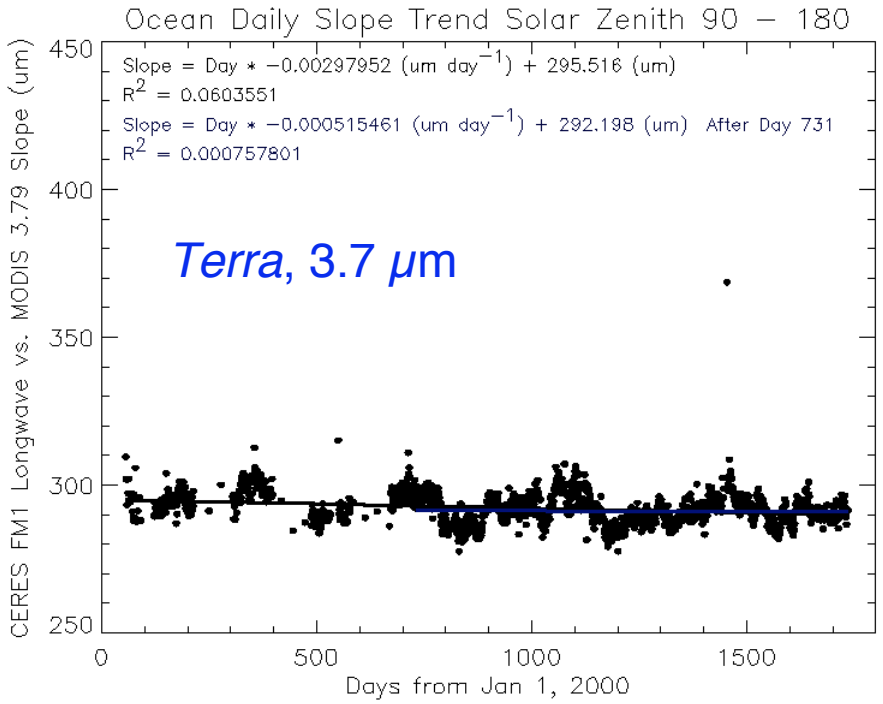


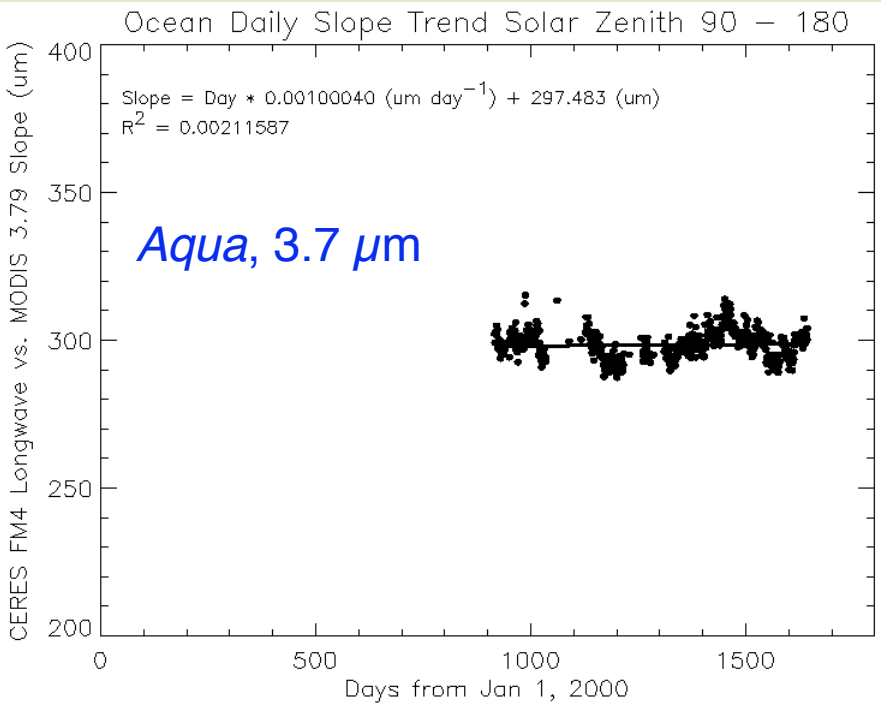


Terra FM1: no trend

Aqua FM4: slight decreasing trend, consistent with VIS

Comparison of CERES SW and MODIS Solar-IR (3.78 μm) Channel, 2000 - 2004





Terra FM1: no trend

Aqua FM4: no trend

***Aqua* colder than *Terra* => more LW for a given radiance**

CALIBRATION STATUS FOR CERES VIRS/MODIS

- ***Terra*** **MODIS VIS up ~ 2% less than Aqua**
  - ***shows up in direct comparisons***
  - ***comparisons with CERES SW fluxes show 1.2% difference***

- ***Terra*** **vs** ***Aqua*** **MODIS 3.7 *μ*m**
  - ***earlier results show Terra 0.7 K higher***
  - ***current results show Terra still higher***
    - *warmer when compared to CERES*

- **IR (10.8 & 12.0 *μ*m) channels show no significant differences**

- **Trend analyses continuing, but need to consider V005 changes**

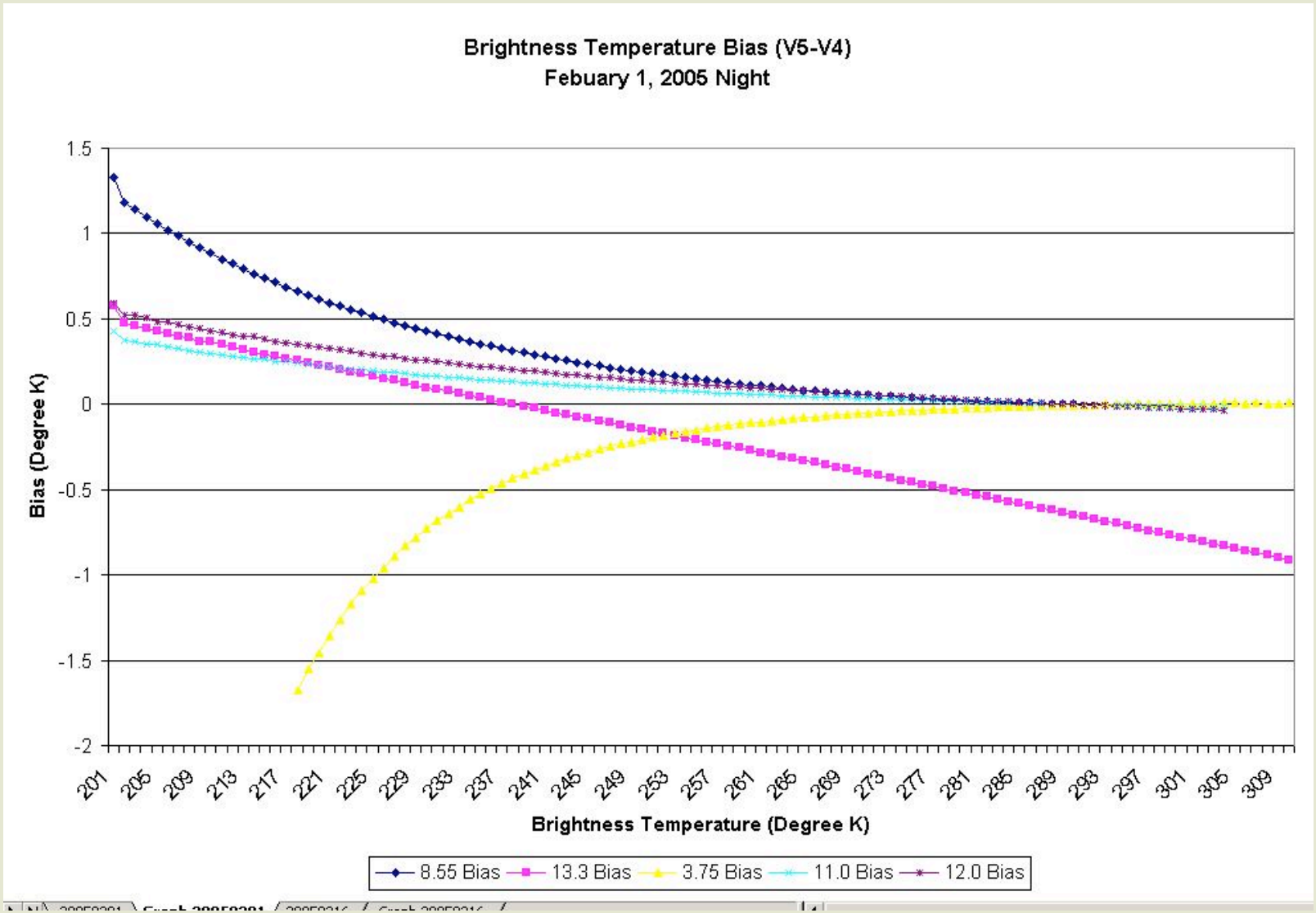
Terra MODIS Version 5

- Each channel calibration slightly different than Version 4

  - supposedly better

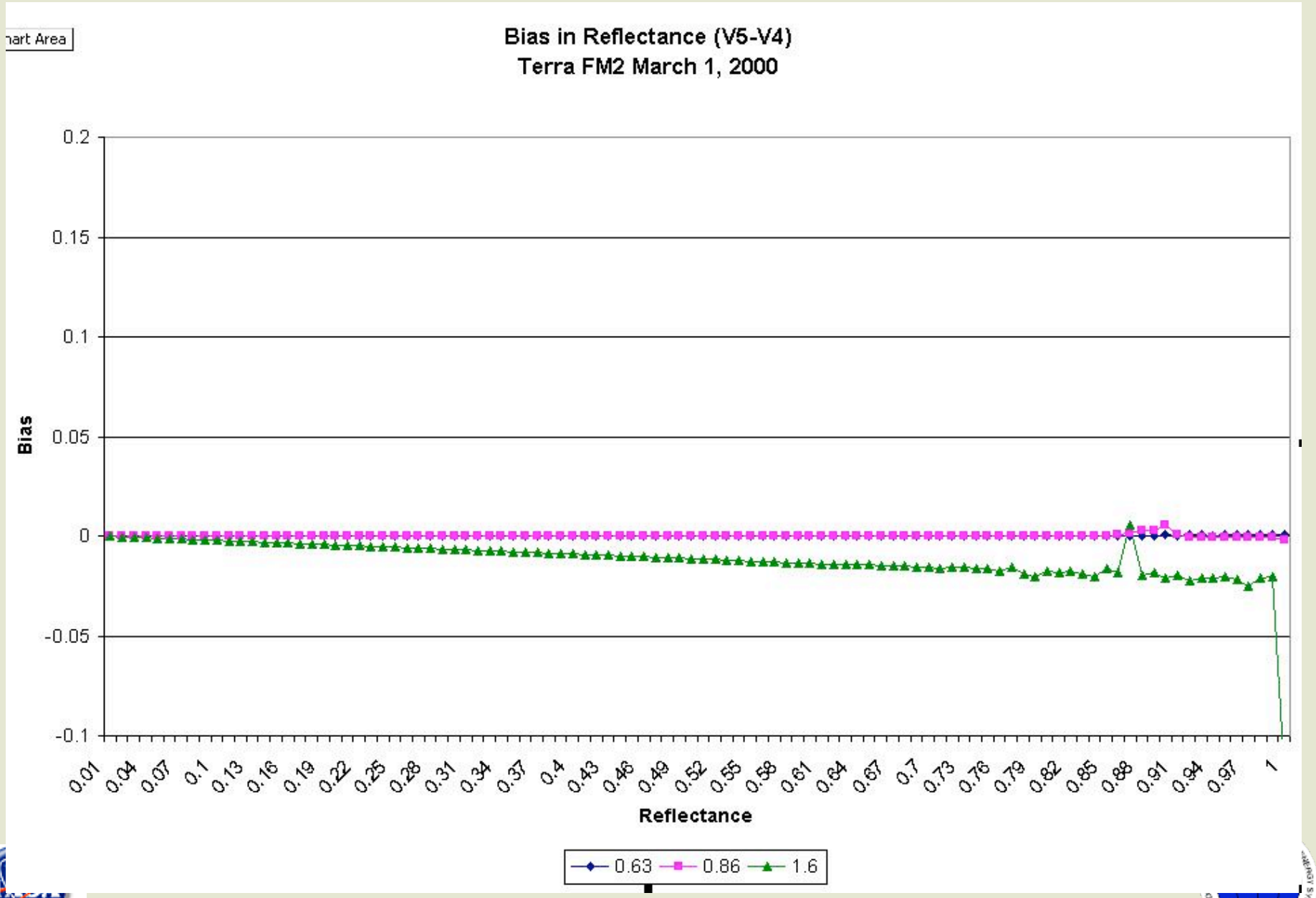
- Initial test run for several days for comparison with V004

Impact of Version 5 on Cloud Properties Using Current Algorithms

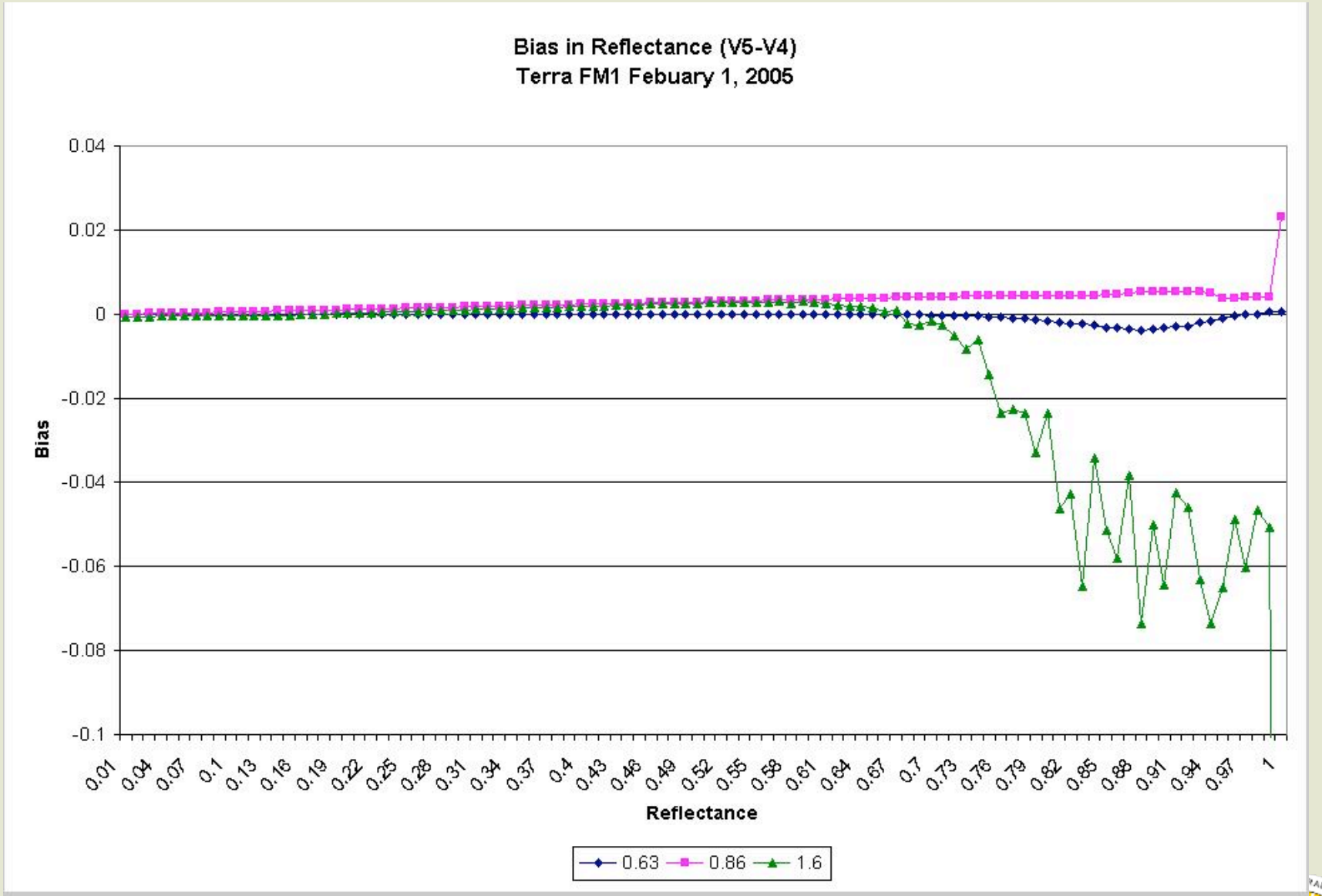


- 3.7 μm colder at T < 285 K: reduce droplet size (day), increase De
- 11, 12 μm warmer at T > 285 K: reduce polar night cloud

Solar Reflectance Channels

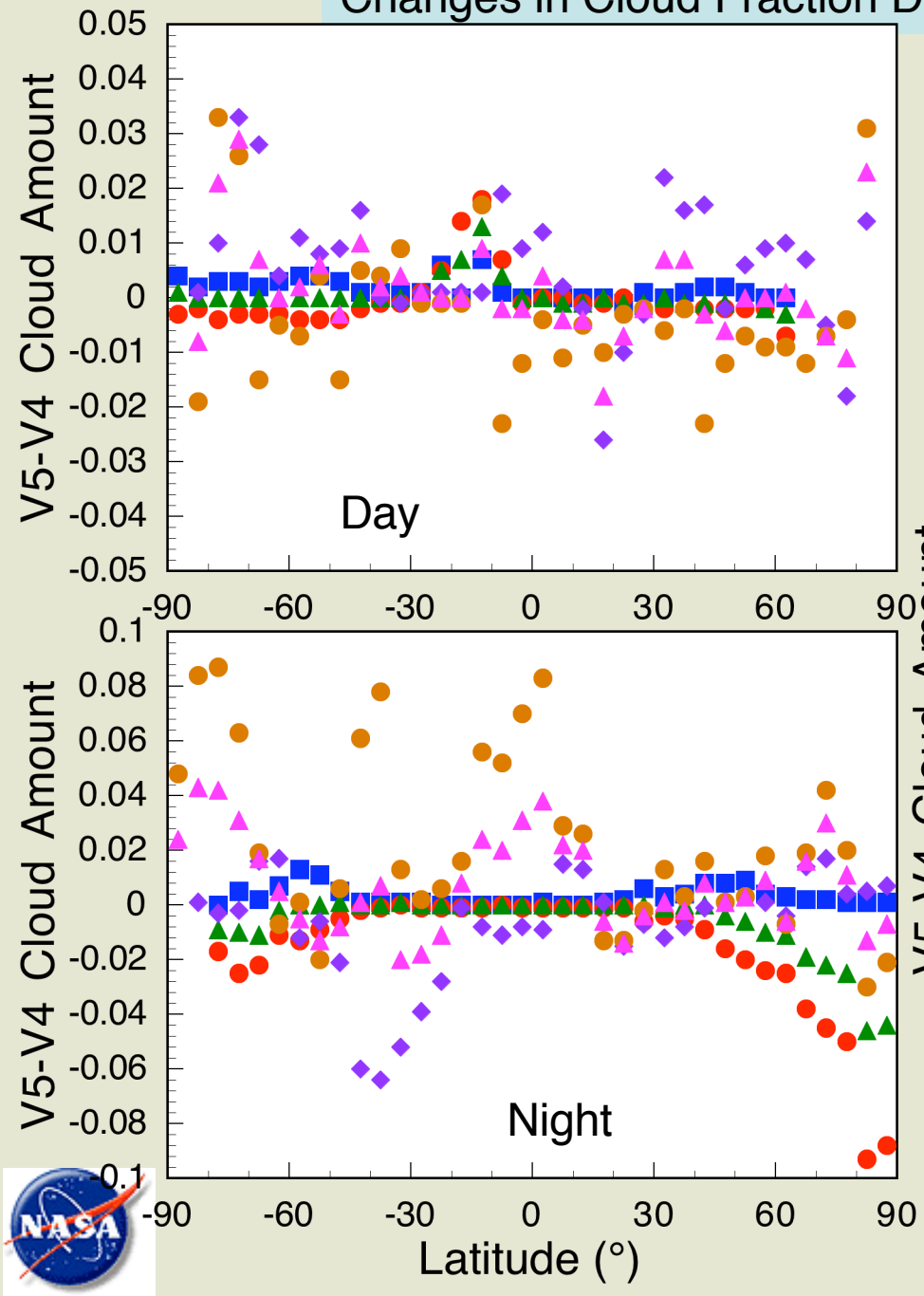


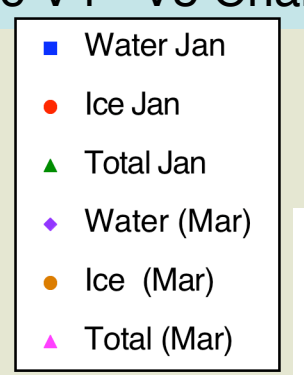
Solar Reflectance Channels



Changes vary with time

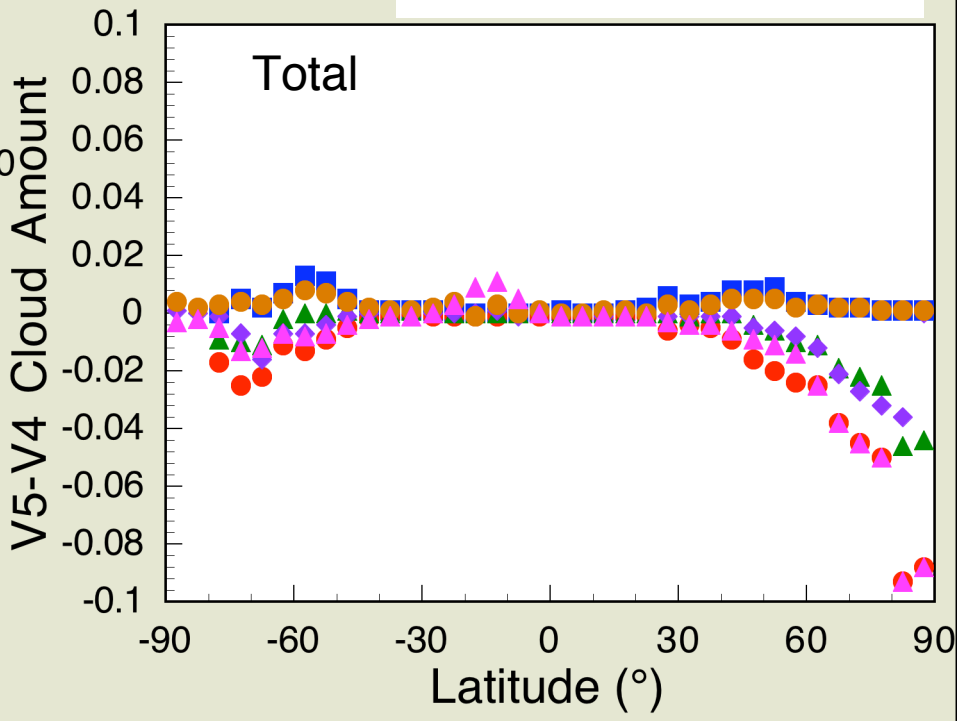
Changes in Cloud Fraction Due to V4 - V5 Change



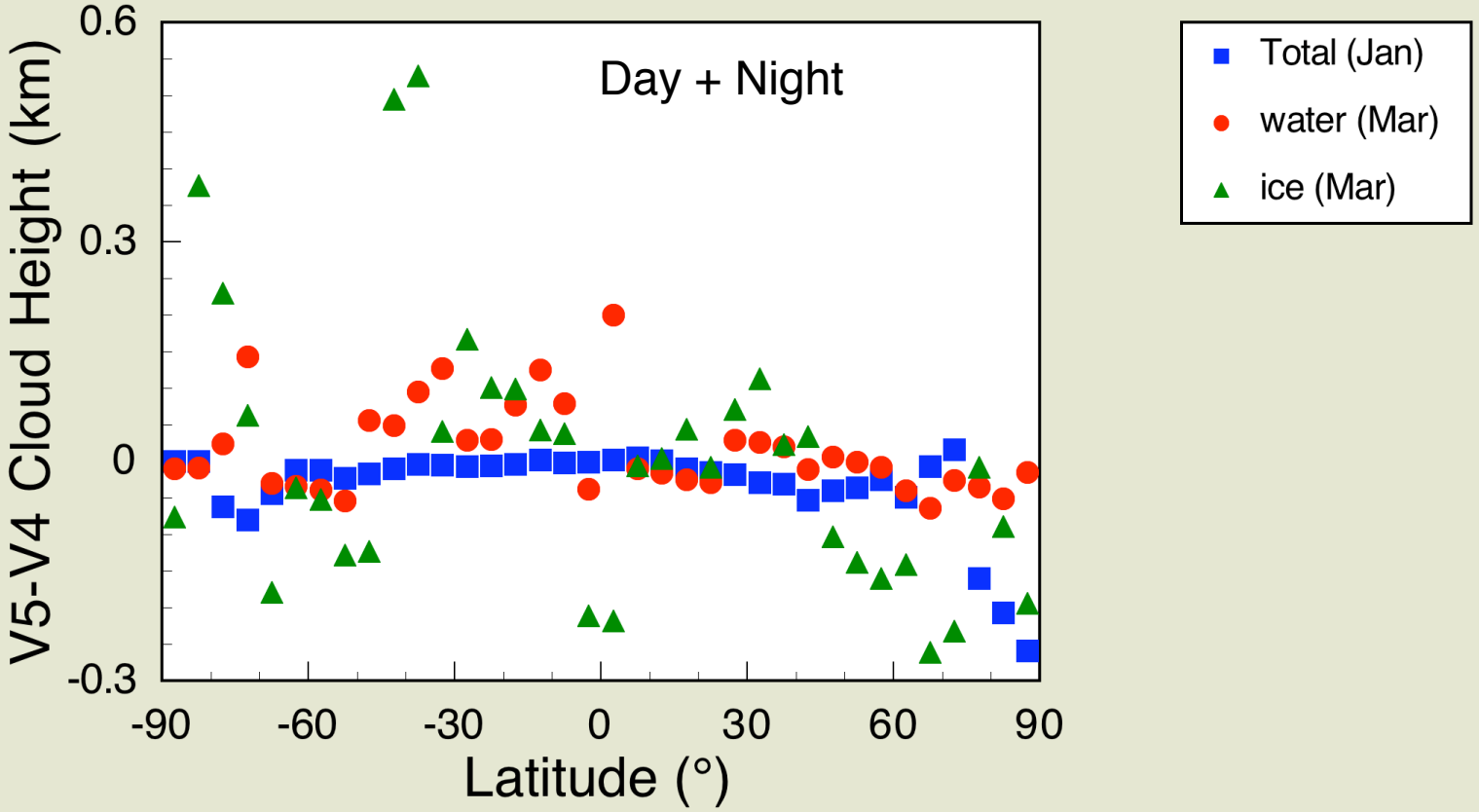


Changes mainly in polar regions at night;

Mostly phase changes elsewhere

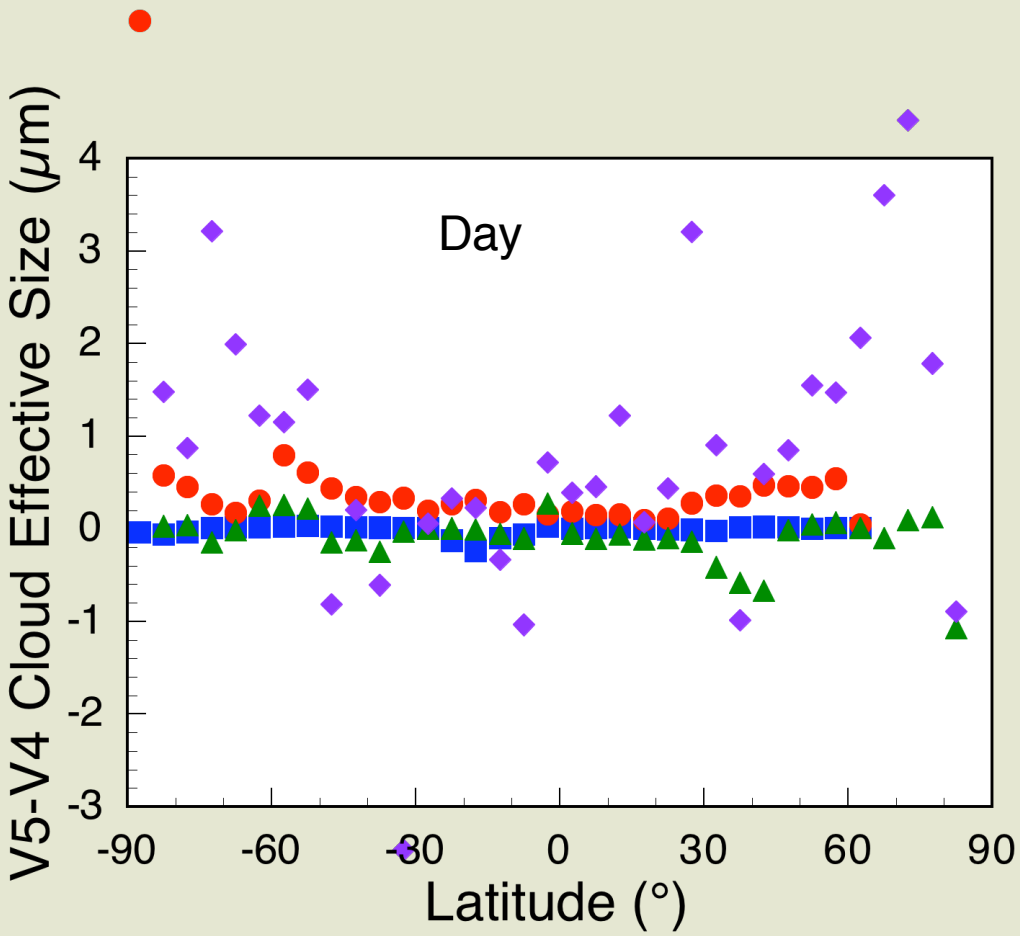


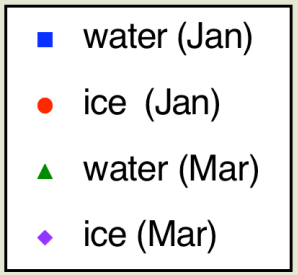
Changes in Cloud Height Due to V4 - V5 Change



Mainly decrease in cloud heights in polar night

Changes in Cloud Particle Size Due to V4 - V5 Change





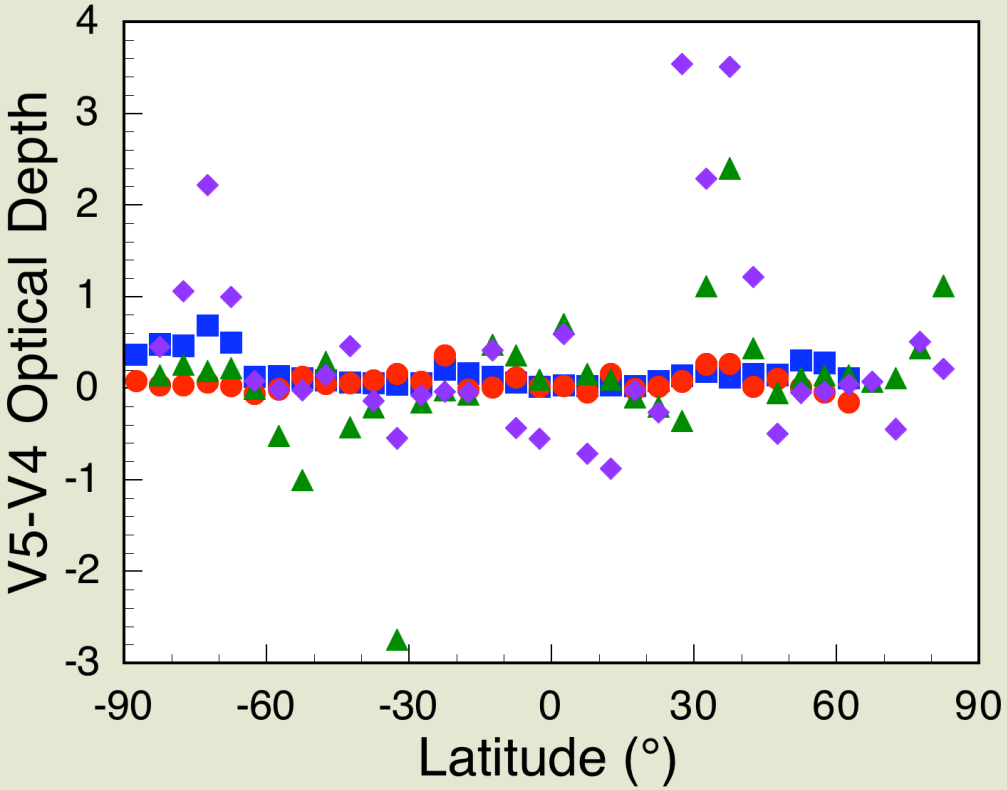
Average Changes

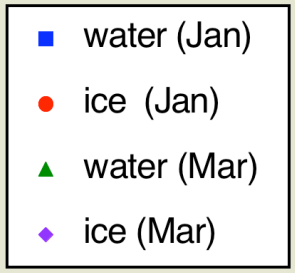
water, re: -0.05 μm

ice, De: 0.65 μm

Largest changes in polar regions

Changes in Cloud Optical Depth Due to V4 - V5 Change





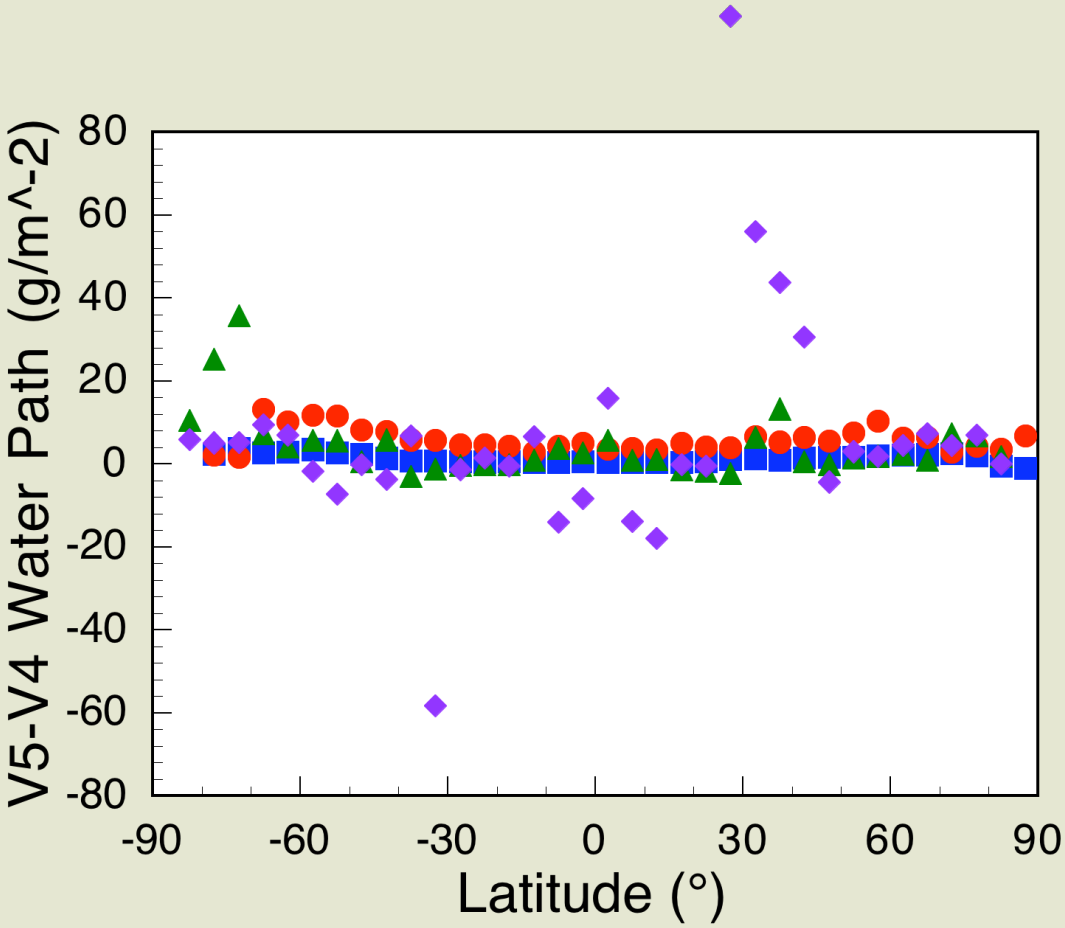
Average Changes

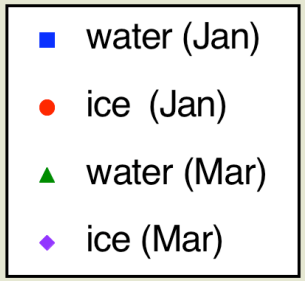
water, 0.13

ice, 0.21

Largest changes in March 2000 and over Antarctica in Jan 2005

Changes in Cloud Water Path Due to V4 - V5 Change





Average Changes

water, 2.8 gm^{-2}

ice, 4.7 gm^{-2}

Largest changes in March 2000 in subtropics

Future for Version 005

- Complete analysis over all seasons
- Alter polar thresholds

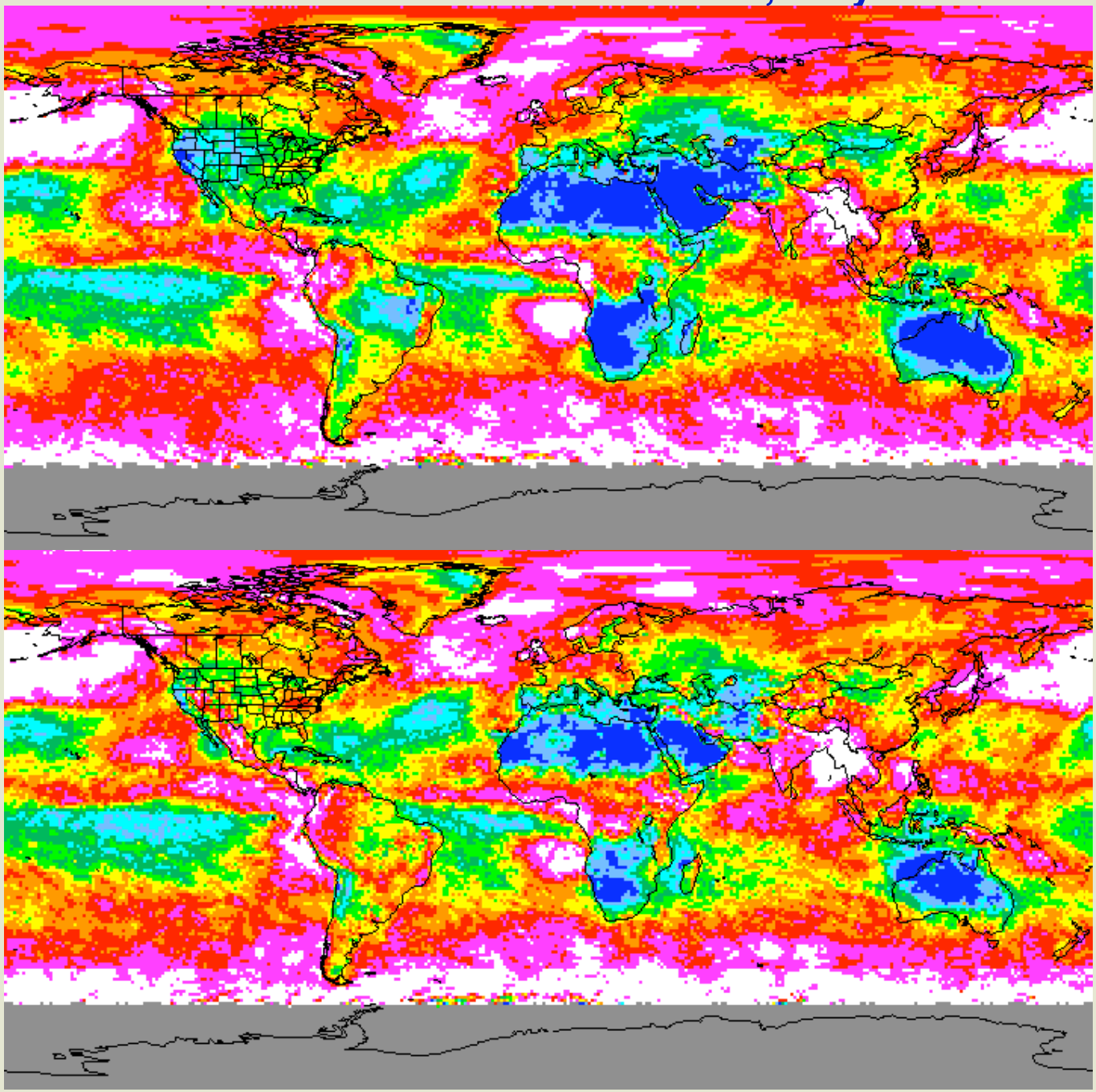
Status of Clouds Processing

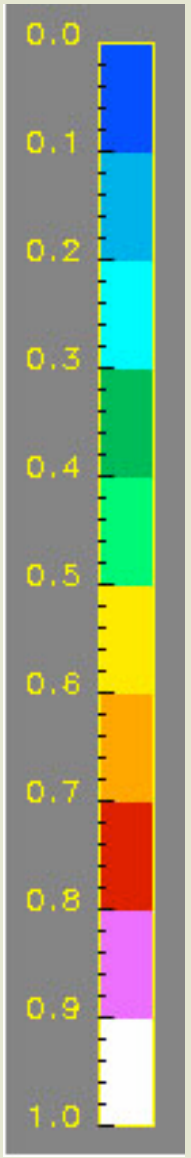
- **TRMM VIRS Edition 2, 37°N - 37°S (Jan 1998 - July 2001)**
  - *SSF with CERES fluxes: Jan - Aug 1998 + Mar 2000*
  - *SSF with no CERES fluxes: remaining months*
- **Terra MODIS Edition 2a, Global (Feb 2000 - Dec 2004)**
  - *all SSF with CERES fluxes*
- **Aqua MODIS Edition 1a, Global (July 2002 - June 2004)**
  - *all SSF with CERES fluxes*

DAYTIME CLOUD AMOUNT, July 2003

Terra

Aqua



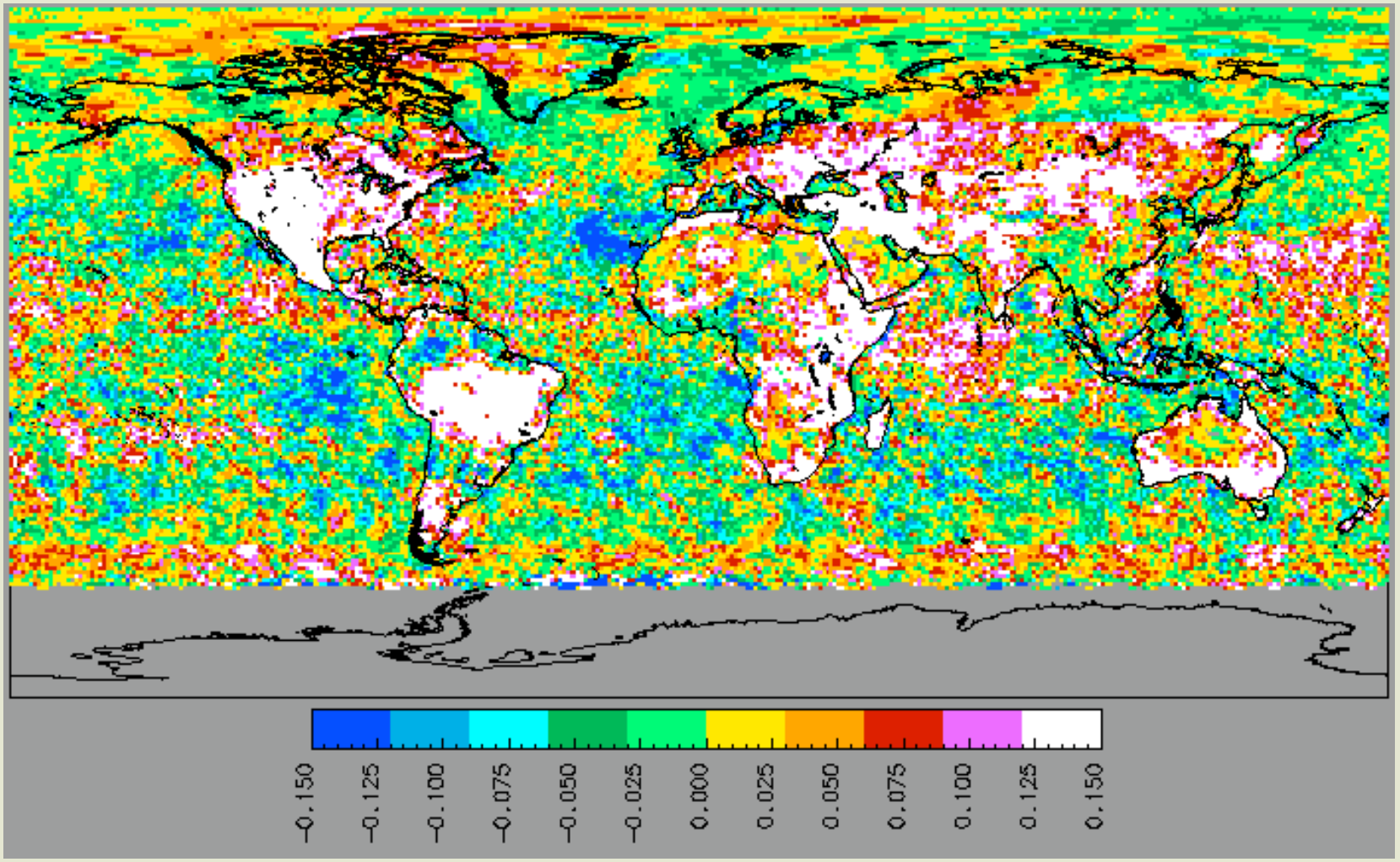


NASA

CERES

DAYTIME CLOUD AMOUNT DIFFERENCE, *Aqua* - *Terra*

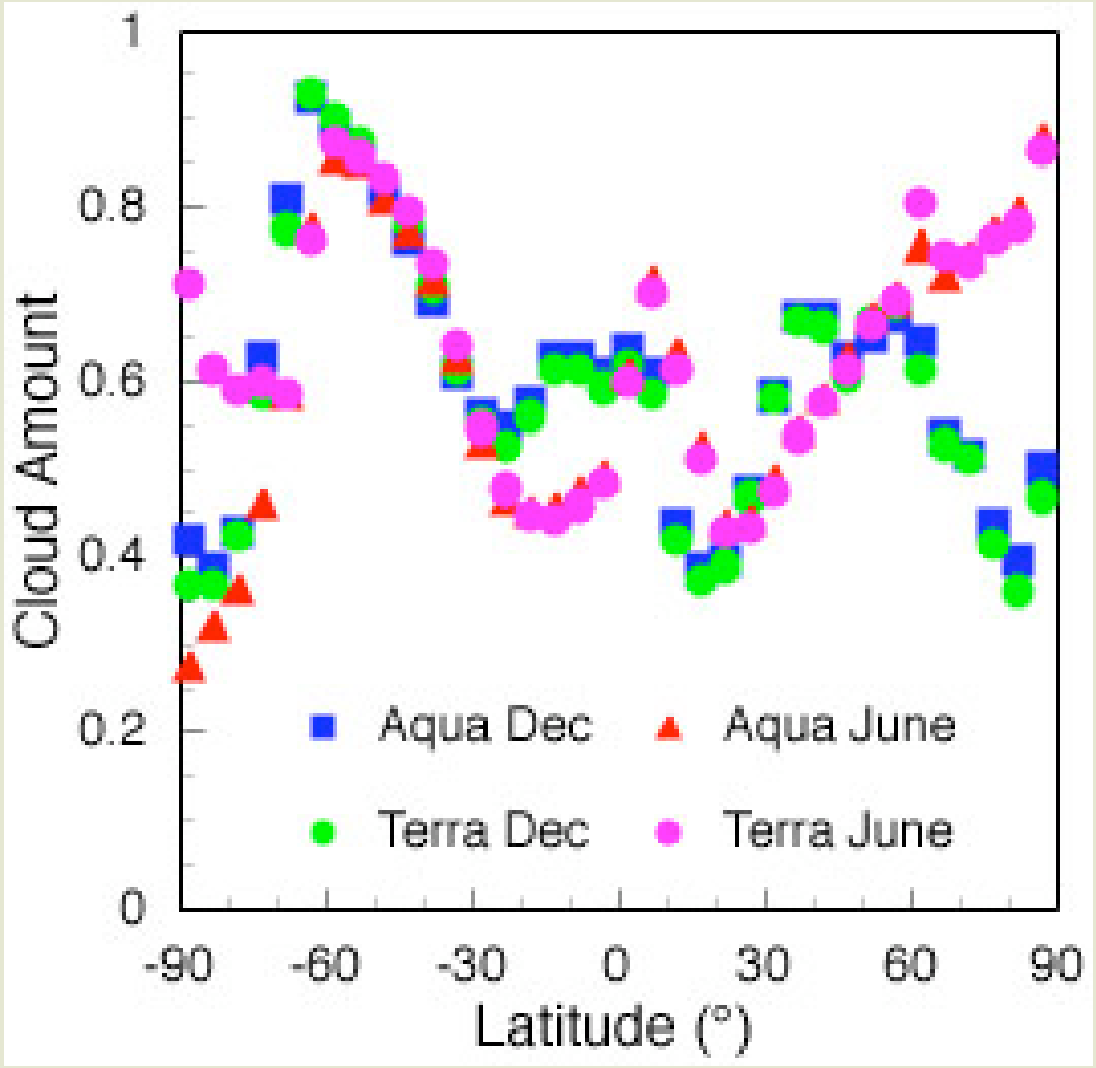
July 2003



Most land areas have positive change,

polar region has own peculiarities

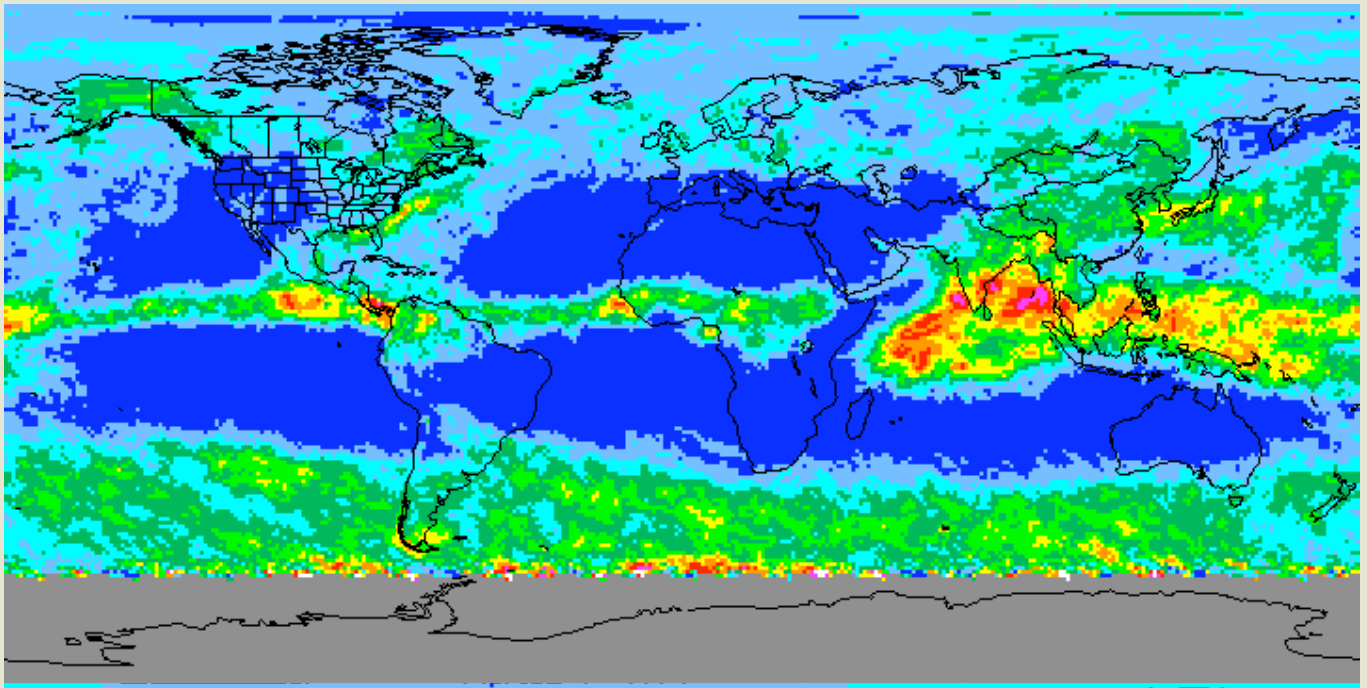
Differences between Aqua 1a and Terra 2 processing



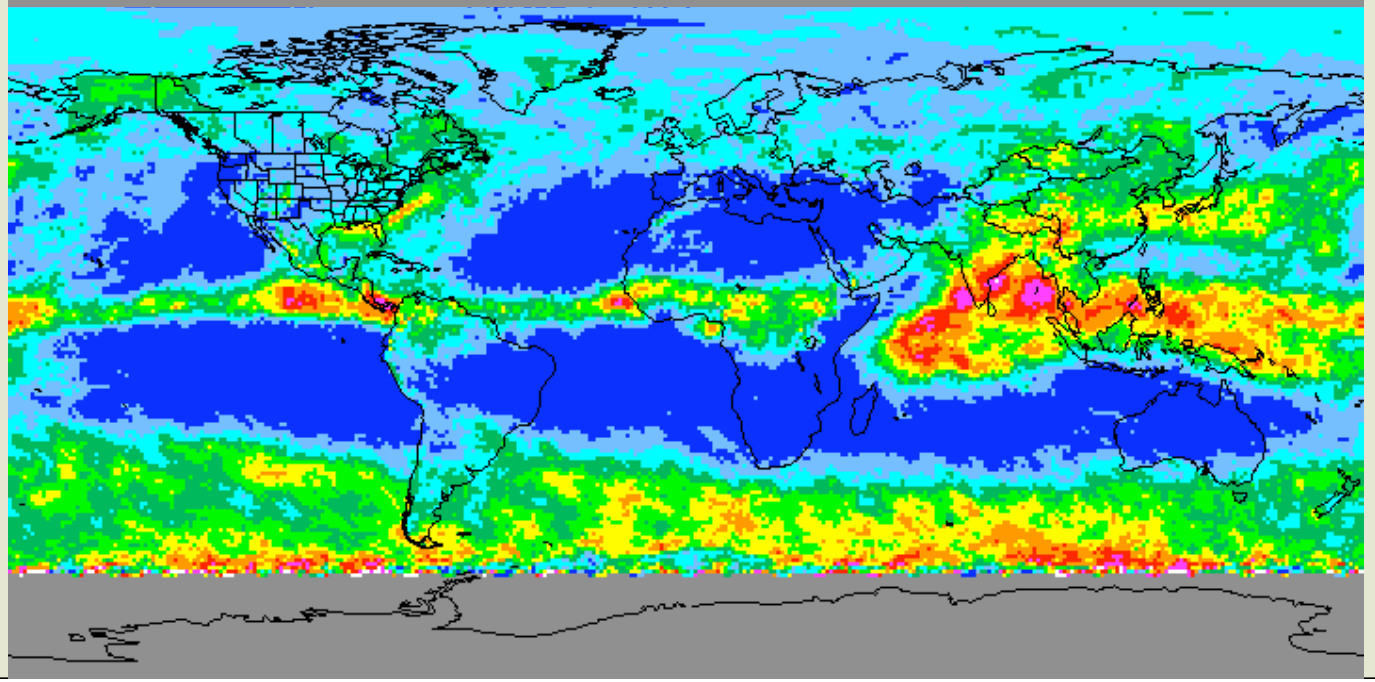
Differences mainly in polar regions

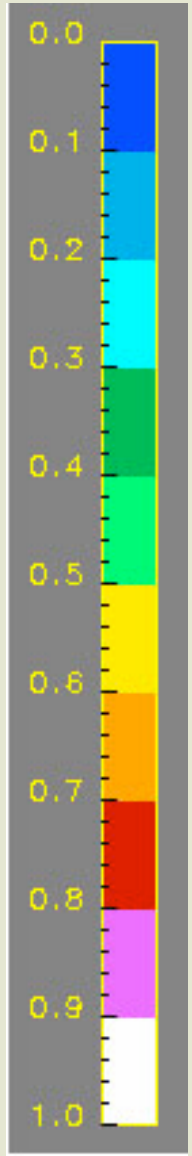
DAYTIME ICE CLOUD AMOUNT, July 2003

Terra



Aqua

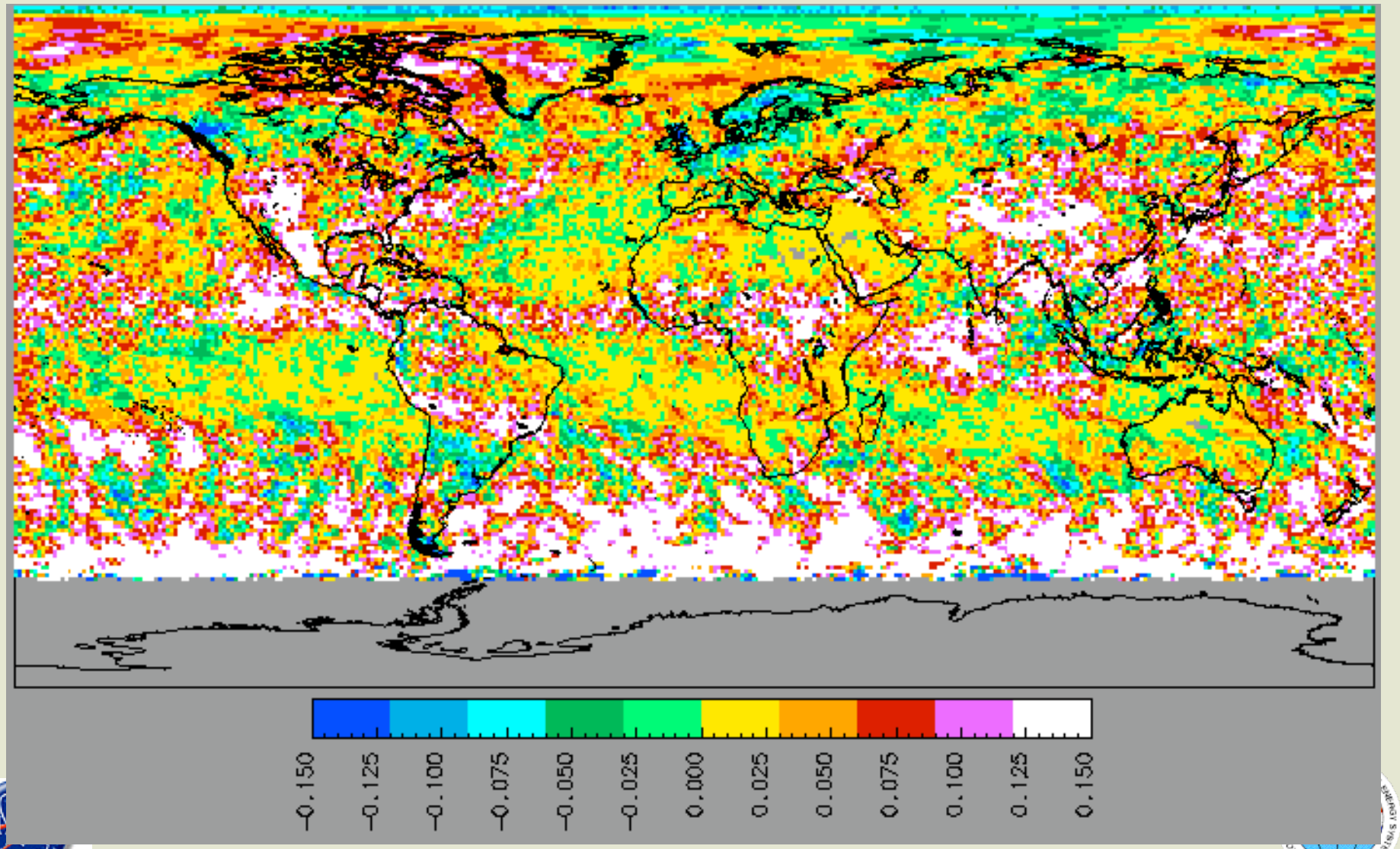




NASA

CERES

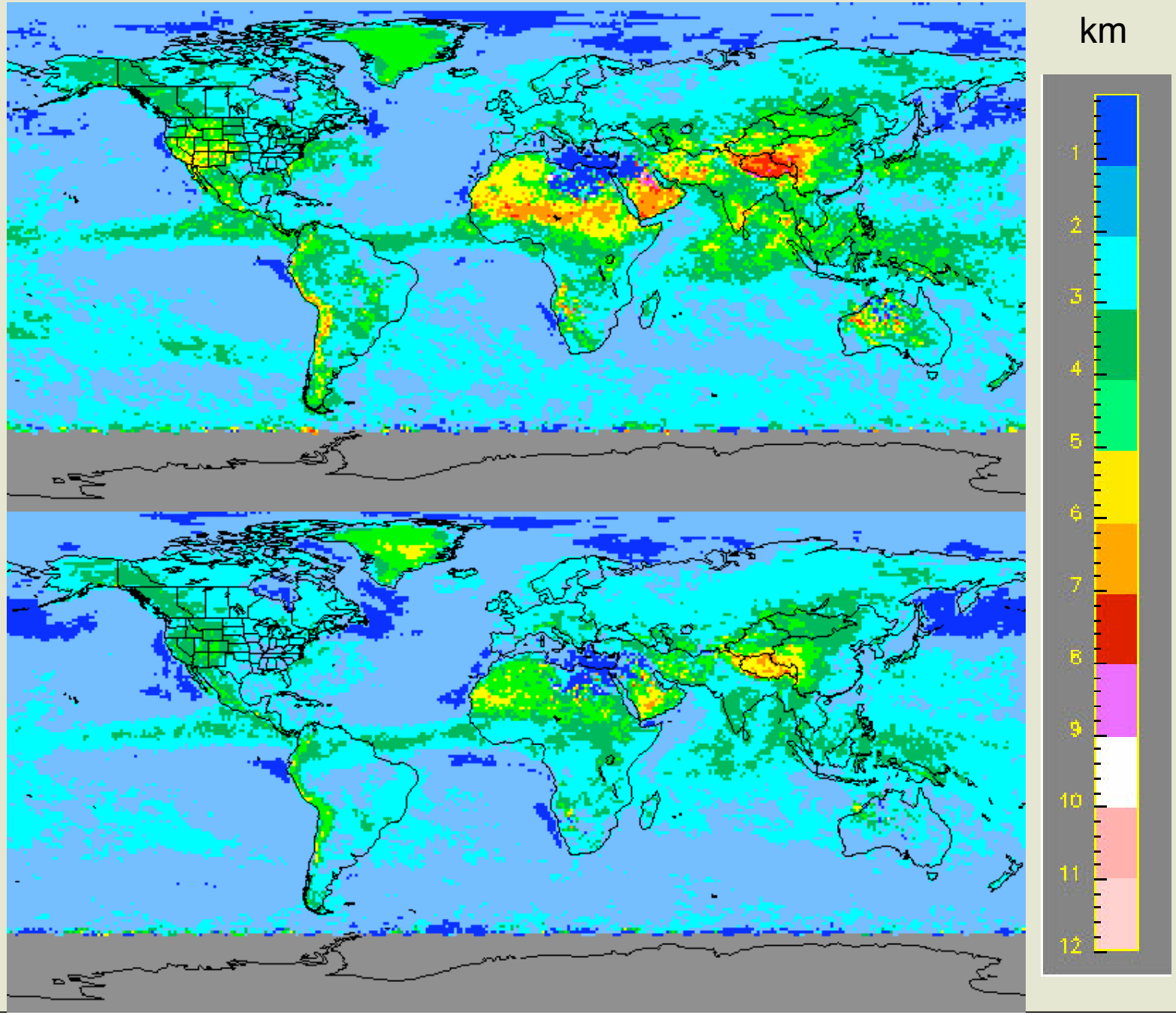
DAYTIME ICE CLOUD AMOUNT DIFFERENCE, Aqua - Terra
July 2003



DAYTIME WATER CLOUD HEIGHT, July 2003

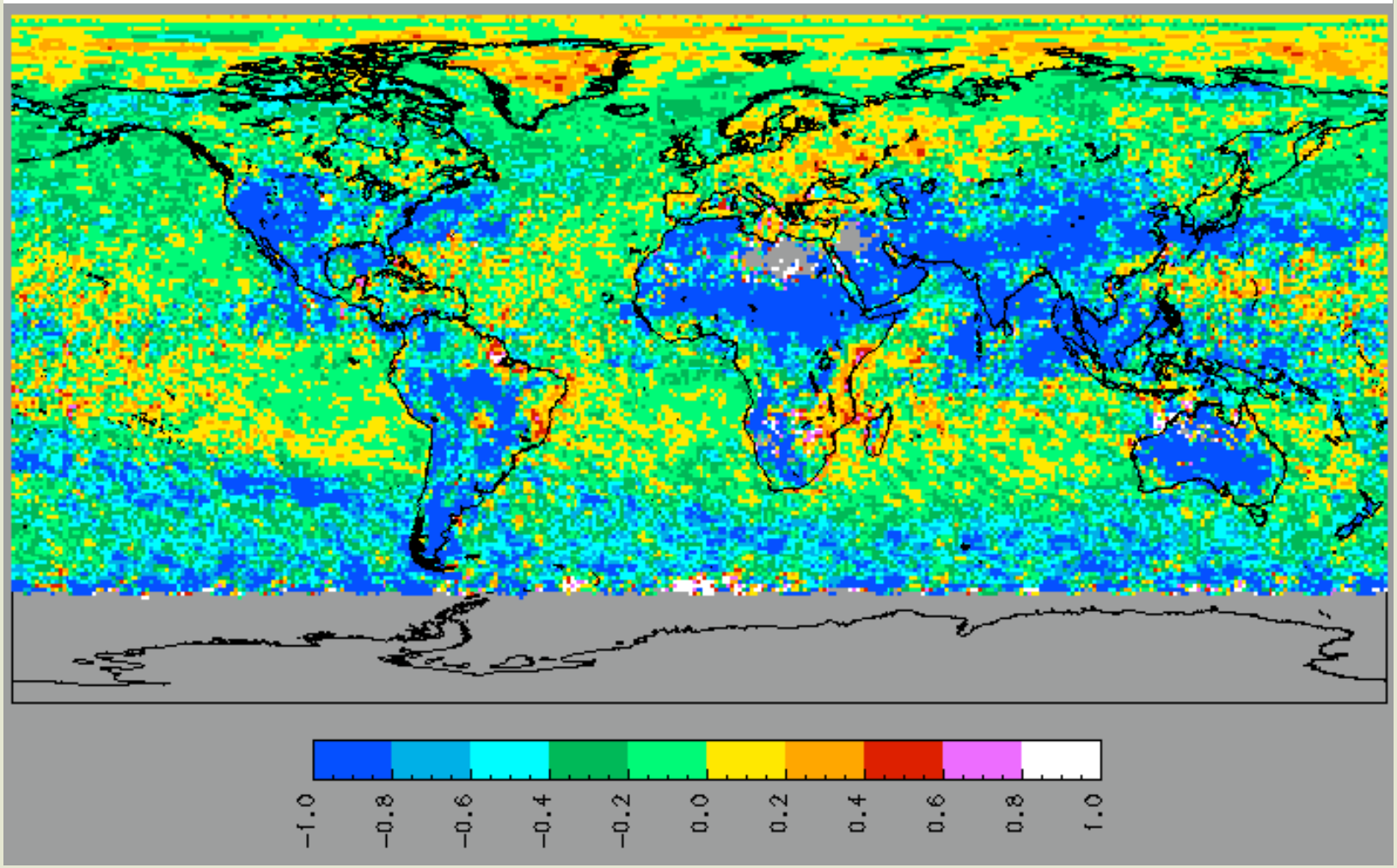
Terra

Aqua

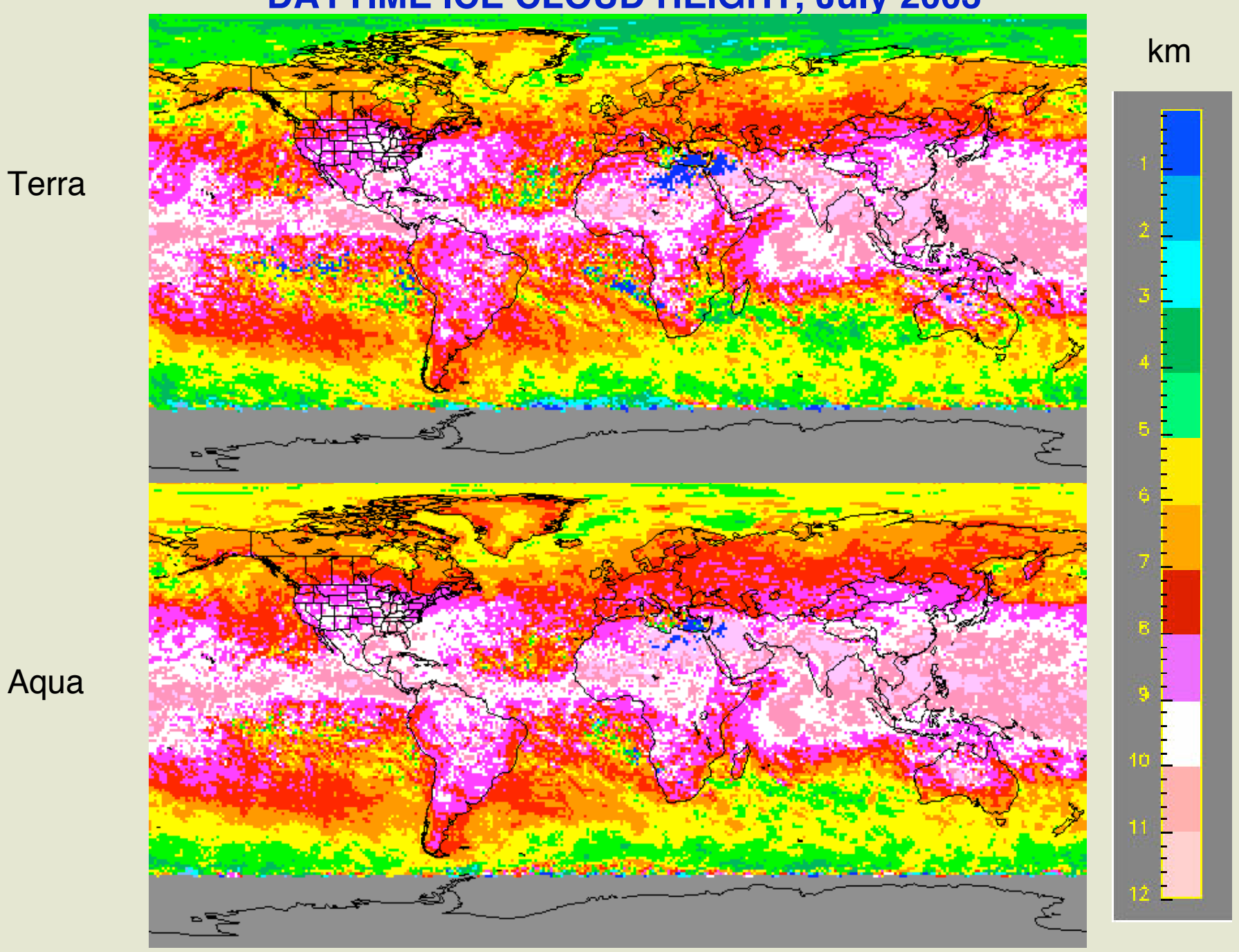


DAYTIME WATER CLOUD HEIGHT DIFFERENCE, Aqua - Terra

July 2003

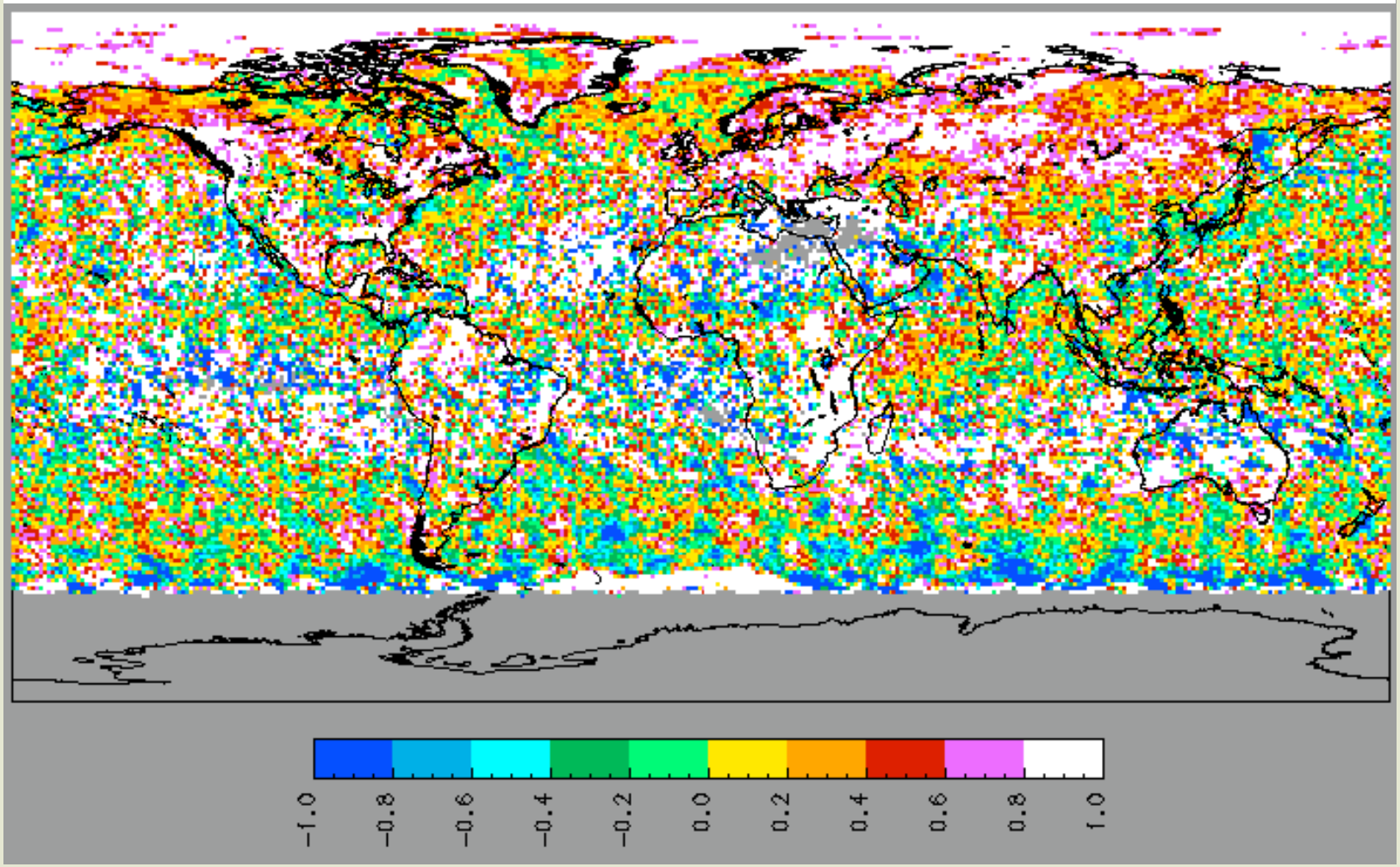


DAYTIME ICE CLOUD HEIGHT, July 2003



DAYTIME WATER CLOUD HEIGHT DIFFERENCE, Aqua - Terra

July 2003

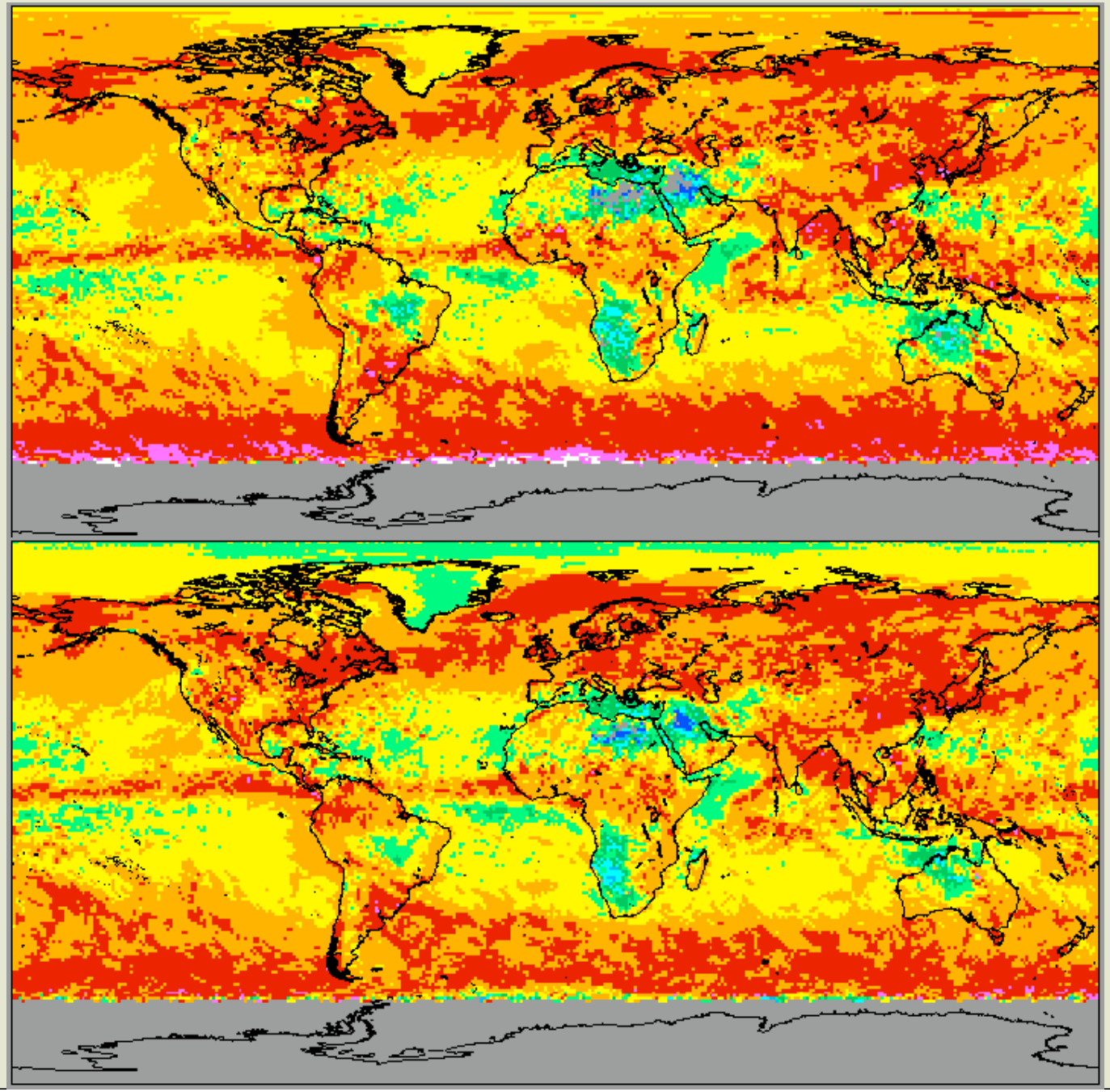


Ice Cloud Height Differences Show Moving Systems in South

DAYTIME TOTAL CLOUD OPT DEPTH, July 2003

Terra

Aqua

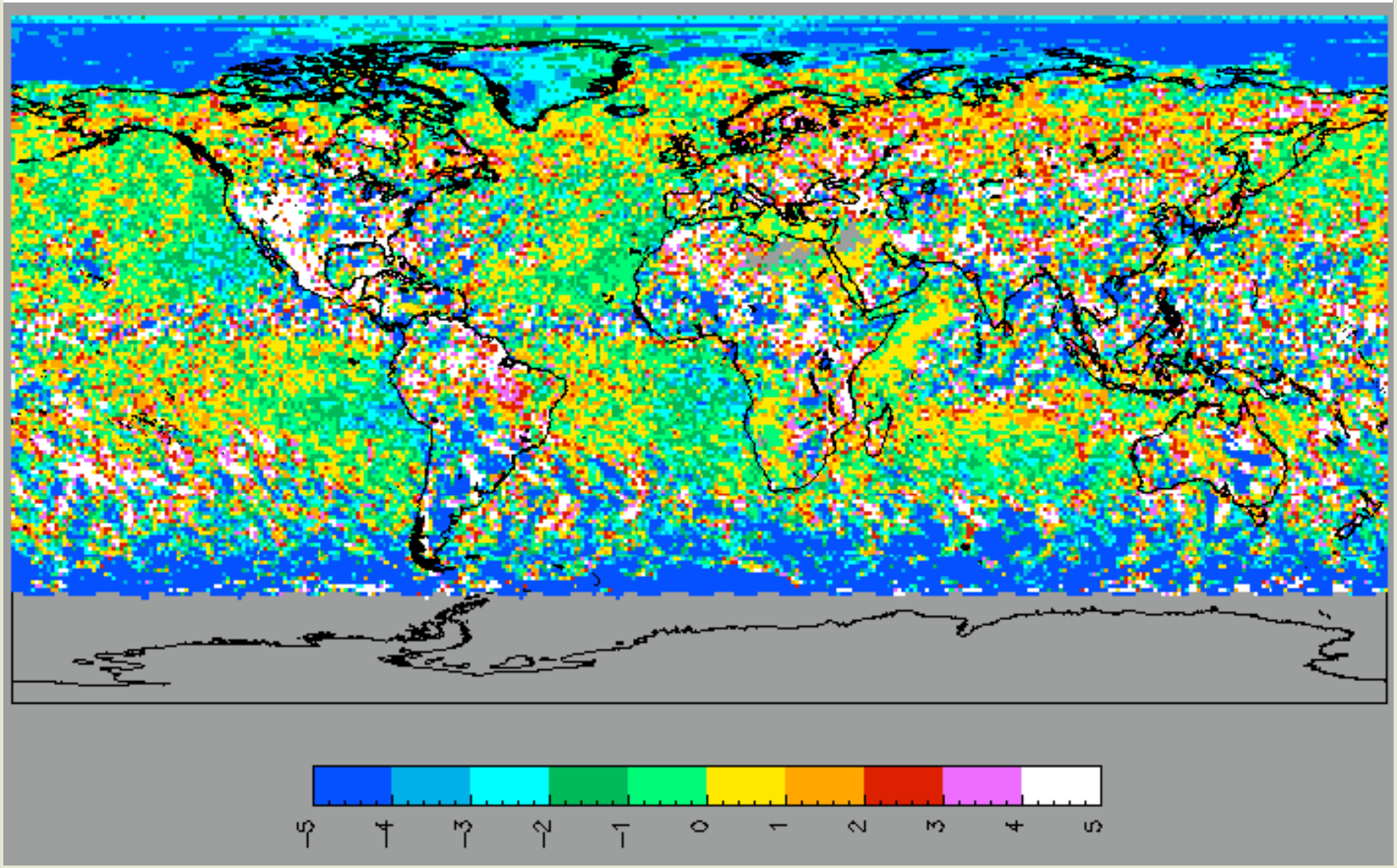


0
.25
.50
1
2
4
8
16
32
64
128

CERES

DAYTIME CLOUD OPTICAL DEPTH DIFFERENCE, Aqua - Terra

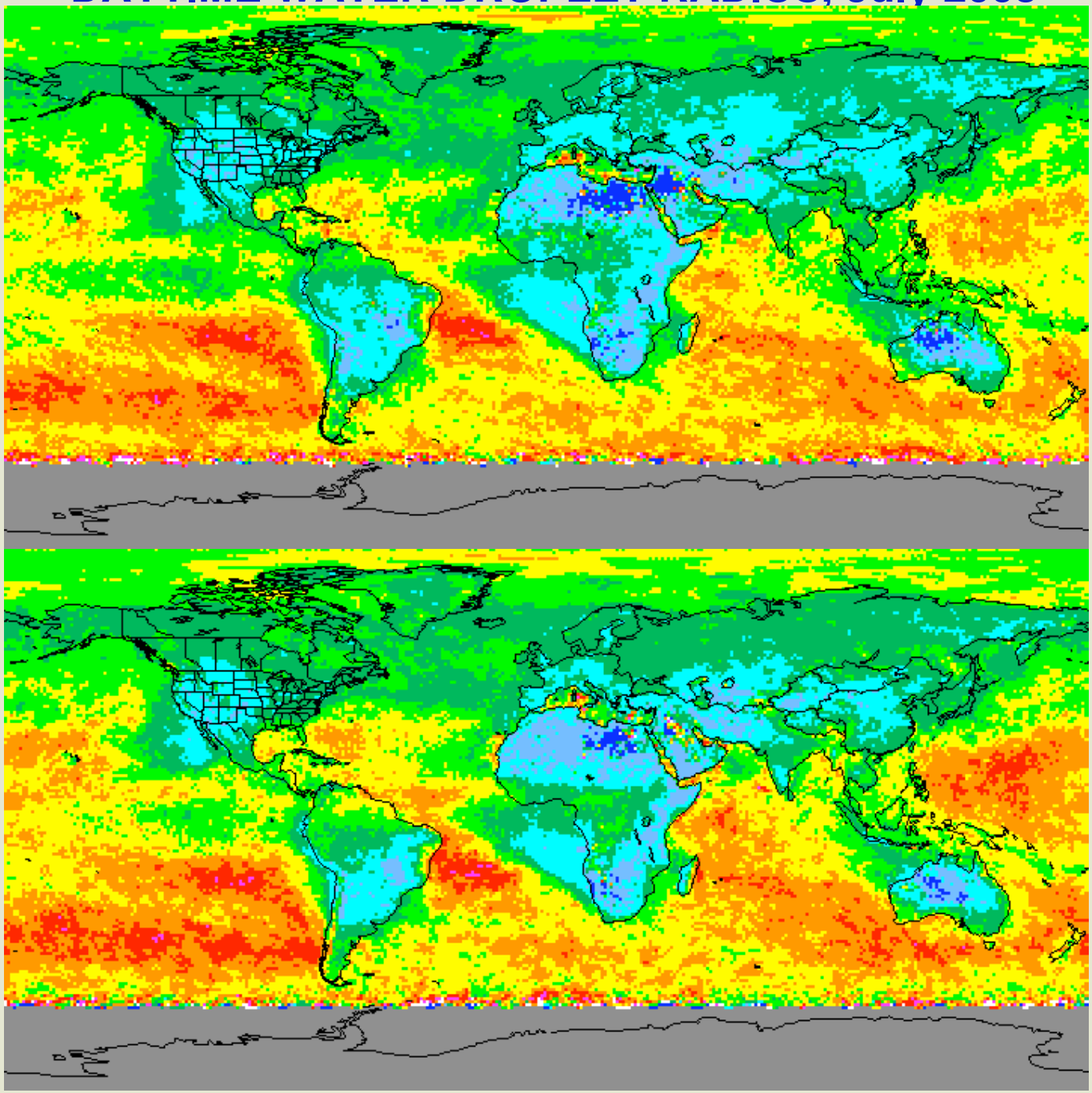
July 2003

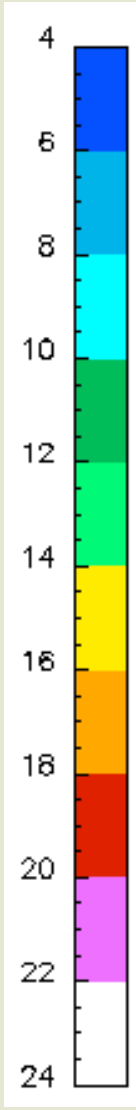


DAYTIME WATER DROPLET RADIUS, July 2003

Terra

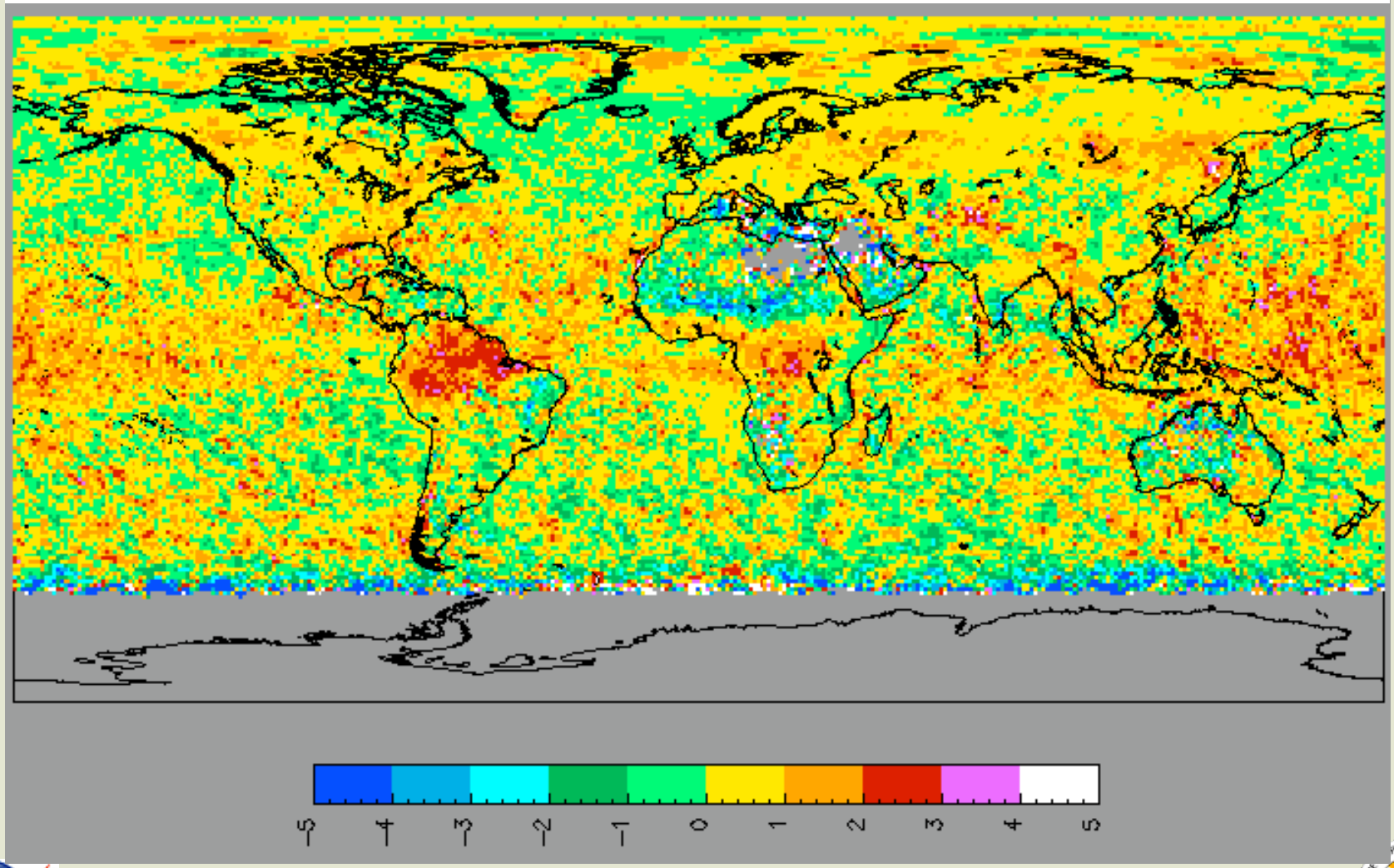
Aqua





DAYTIME CLOUD DROPLET SIZE DIFFERENCE, Aqua - Terra

July 2003

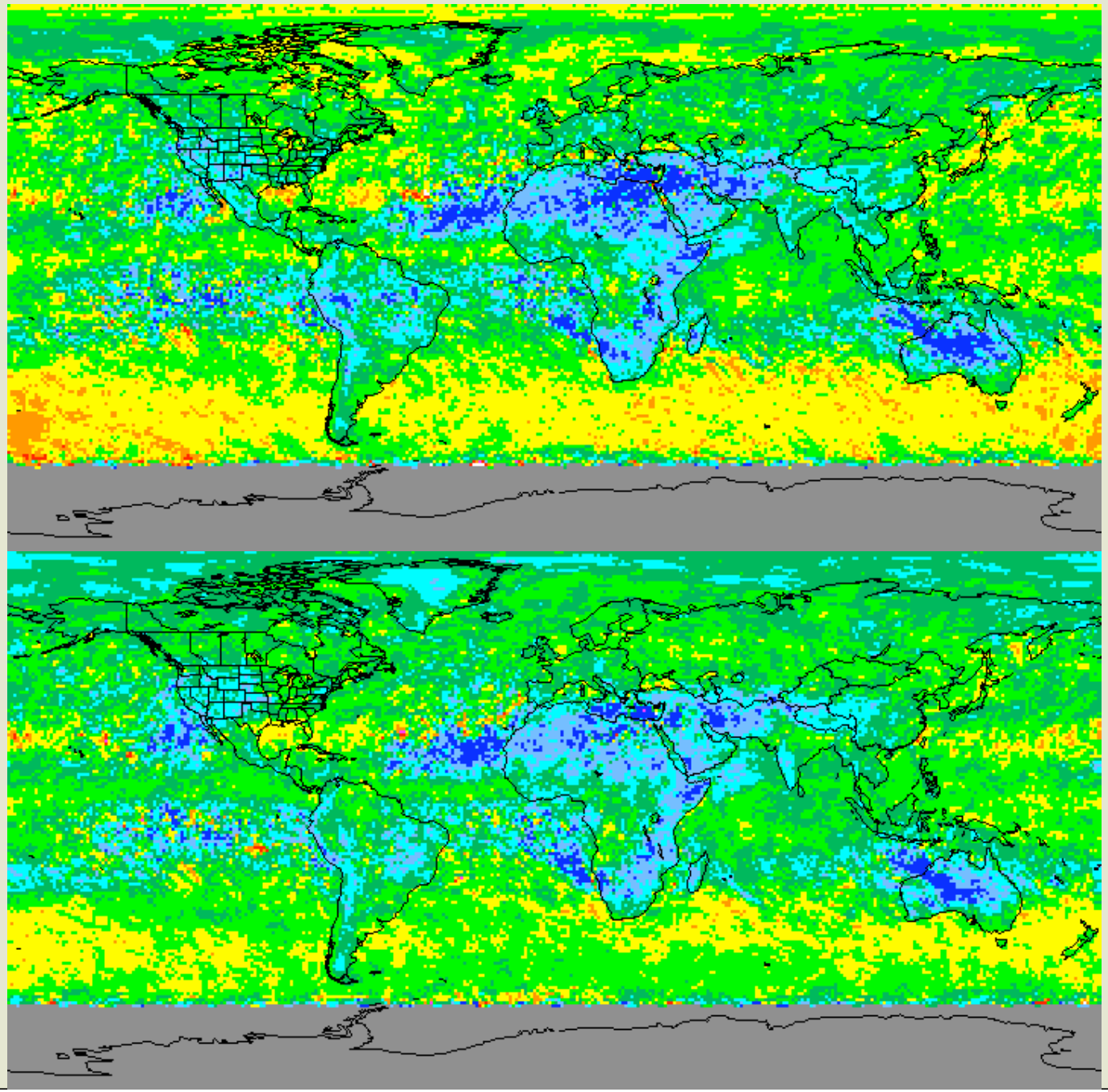


Aqua ~0.7 μm larger than Terra

DAYTIME ICE CRYSTAL DIAMETER, July 2003

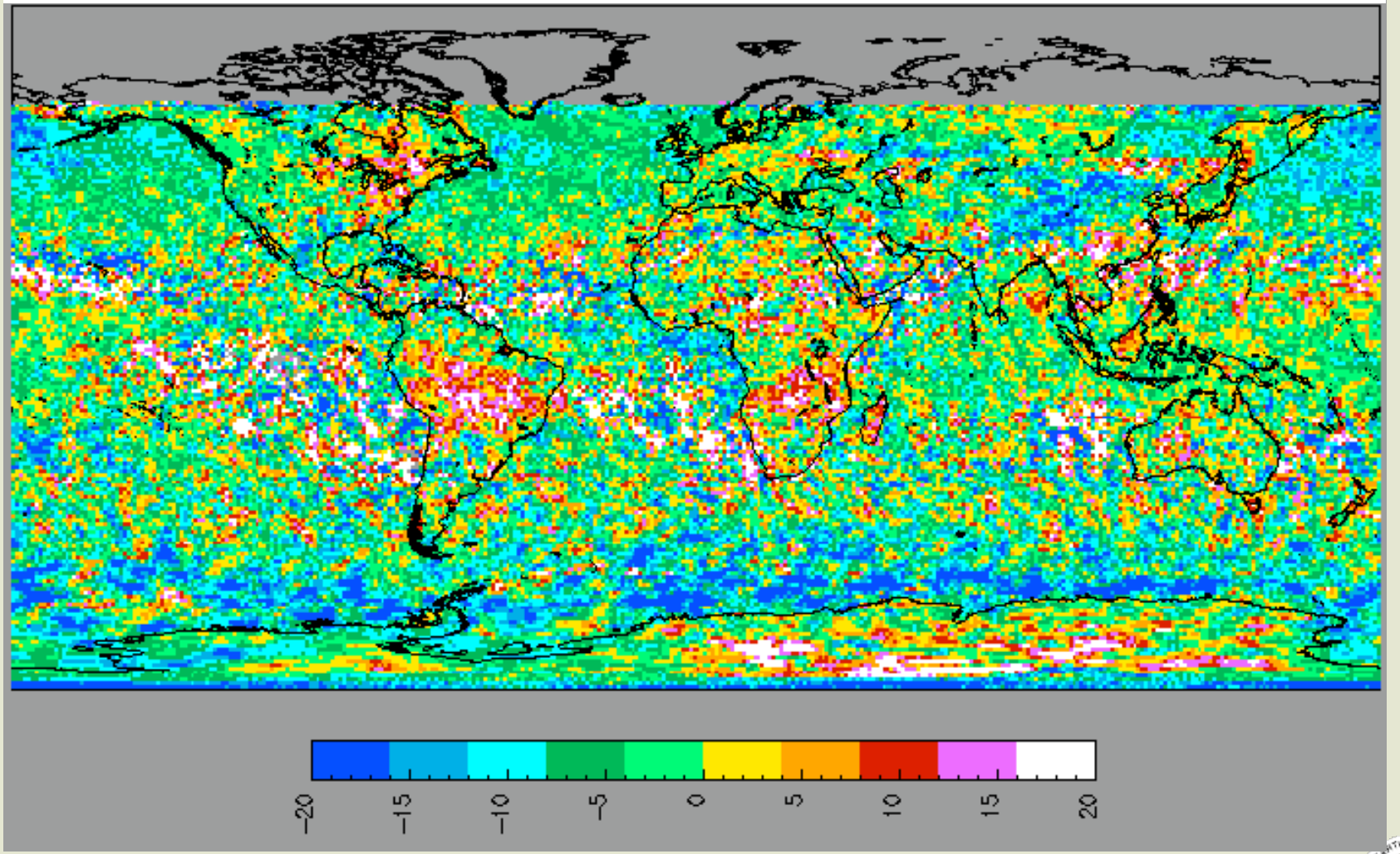
Terra

Aqua



DAYTIME ICE CRYSTAL SIZE DIFFERENCE, Aqua - Terra

July 2003

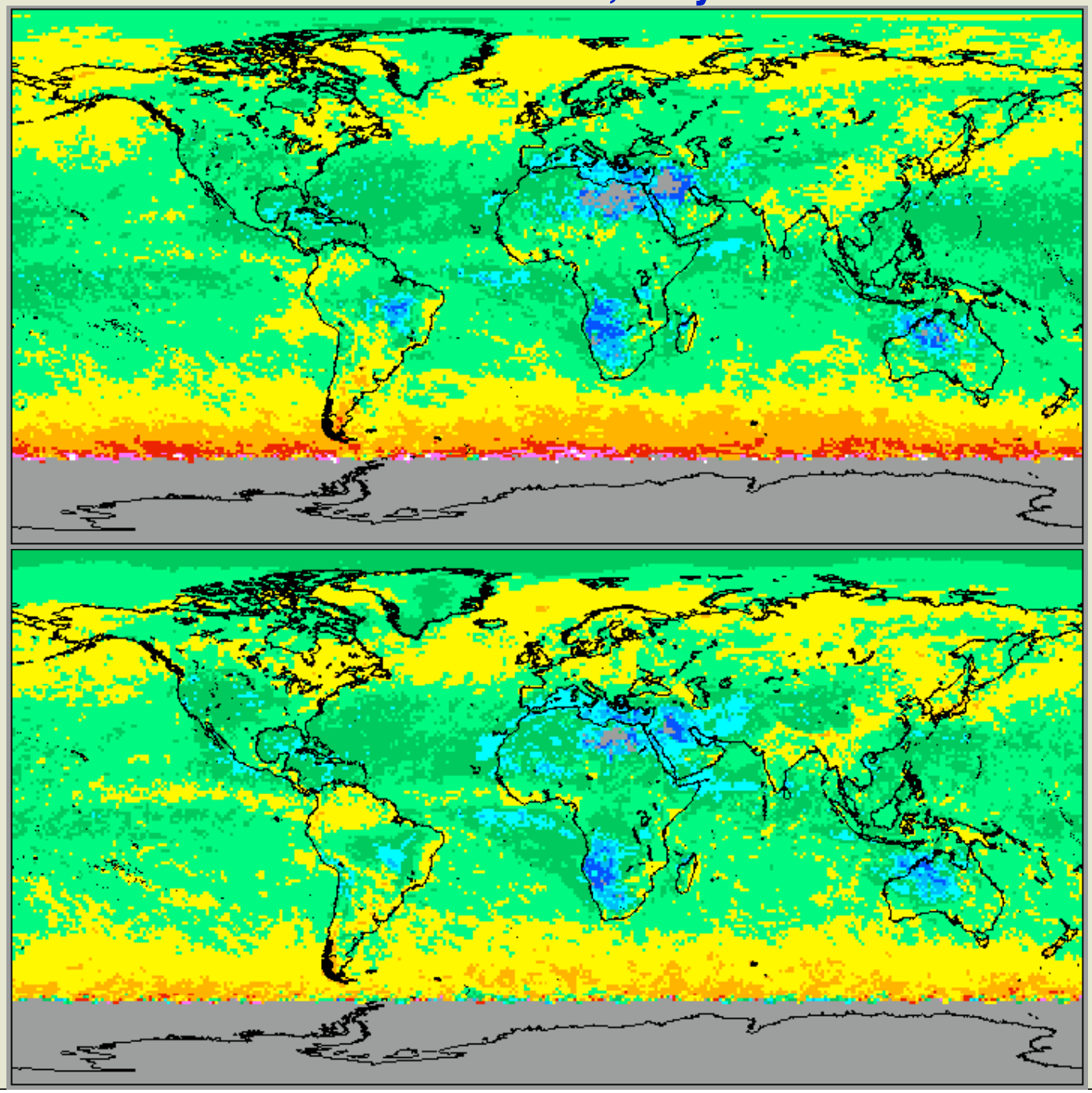


Aqua ~0.7 μm larger than Terra

DAYTIME LWP, July 2003

Terra

Aqua

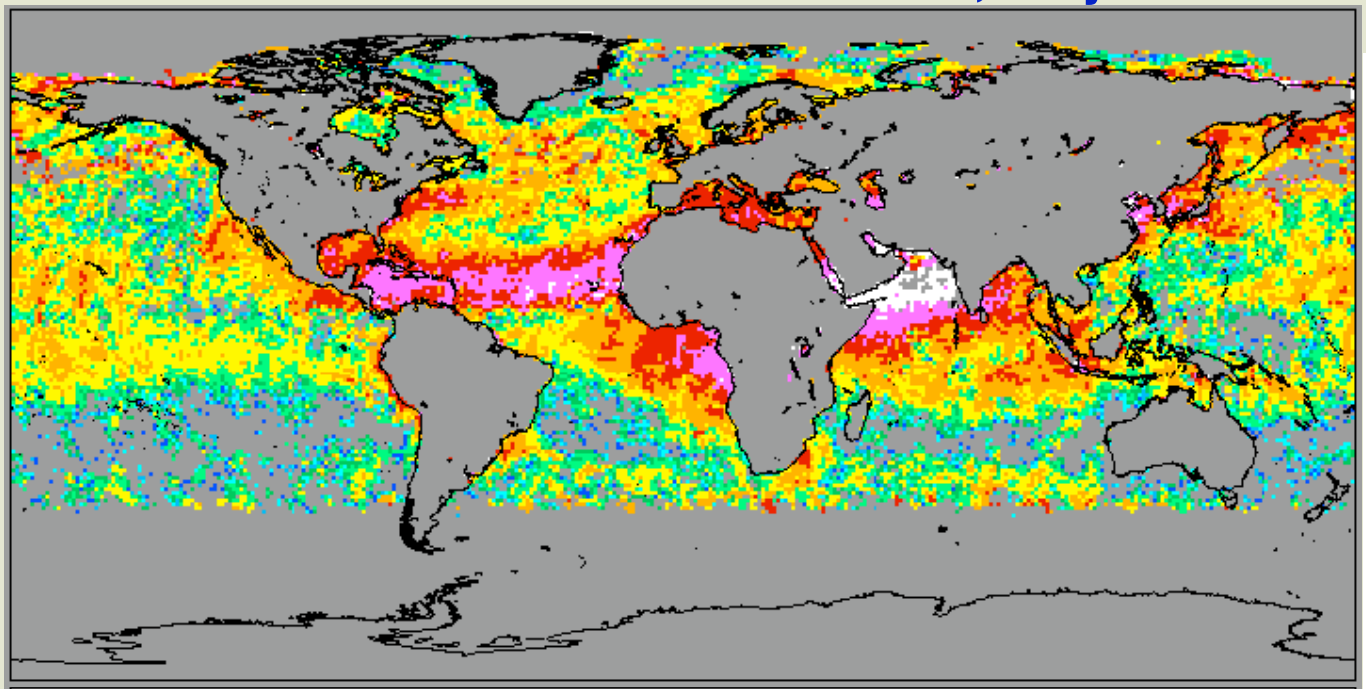


gm^{-2}

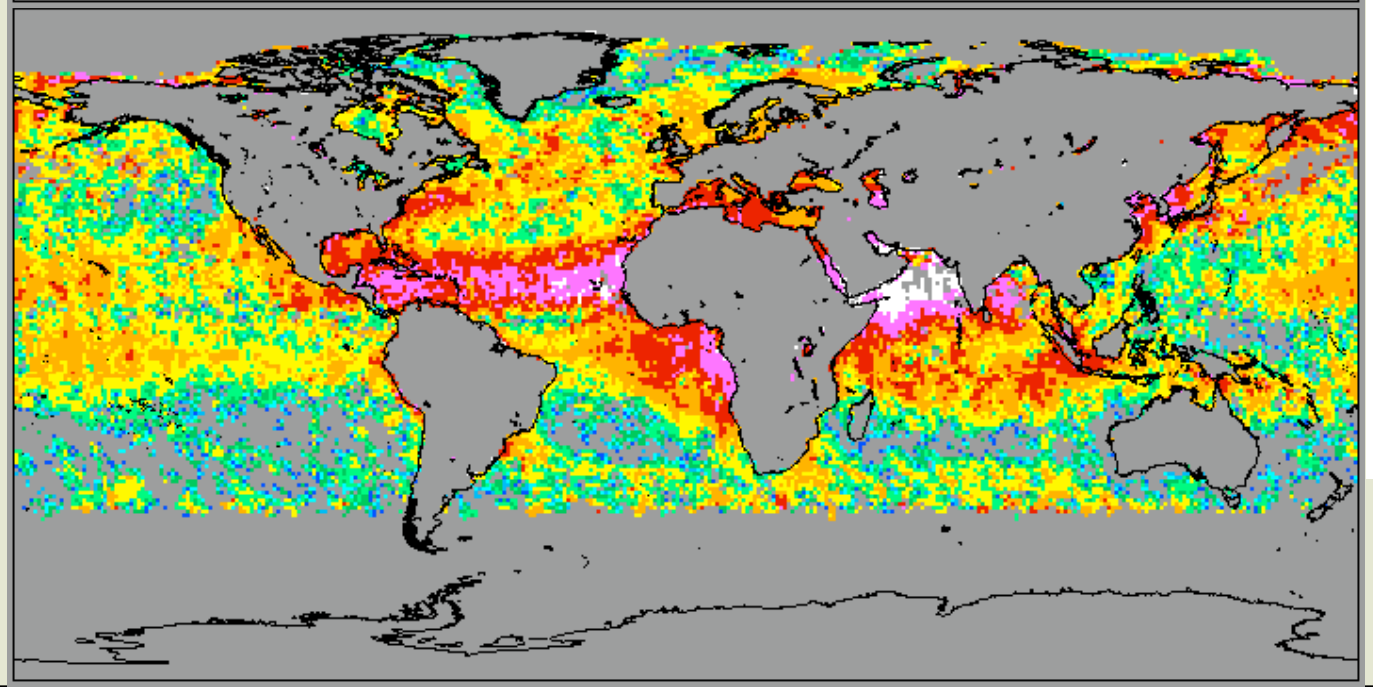
0
20
40
60
80
100
120
140
160
180
200

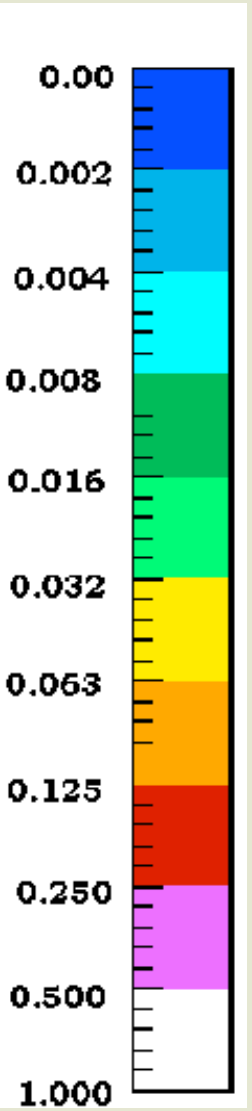
AEROSOL OPTICAL THICKNESS, July 2003

Terra



Aqua





SUMMARY OF TERRA-AQUA CONSISTENCY

- Cloud fractions very consistent in pattern and magnitude
  - some differences over poles (2.13 vs 1.6 μm)
  - night most consistent
- More ice clouds from Aqua
  - probably thin cirrus and LBTM impact, some diurnal
  - lower ice OD, worse over poles
- Lower water cloud heights, higher ice cloud
  - some diurnal, some thin cirrus check
- Otherwise very consistent retrievals
  - thin cirrus check needs more investigation

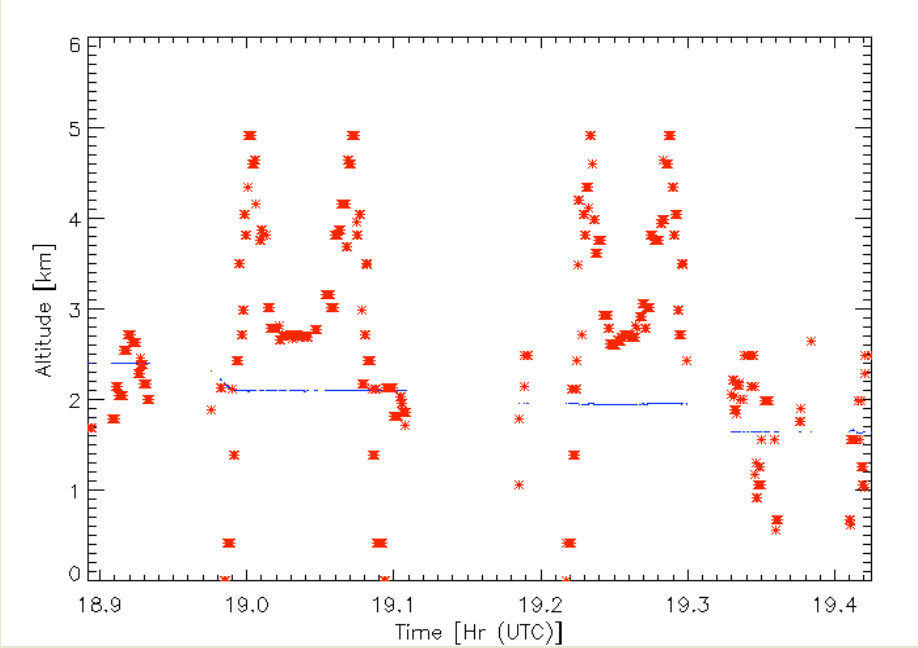
VALIDATION

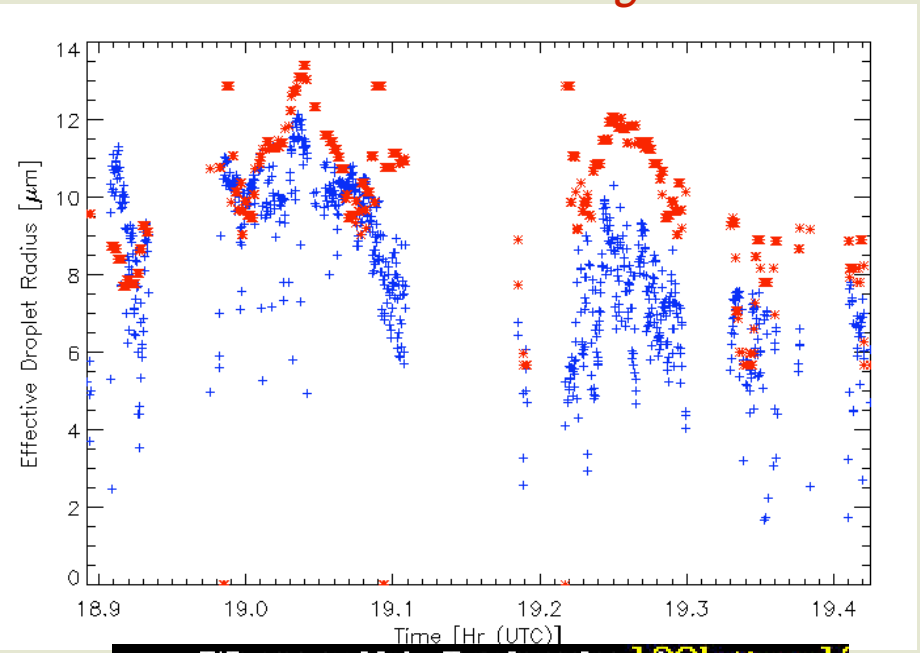
- Comparisons with surface and aircraft observations
- Dual angle views
- Comparisons with other satellite instruments

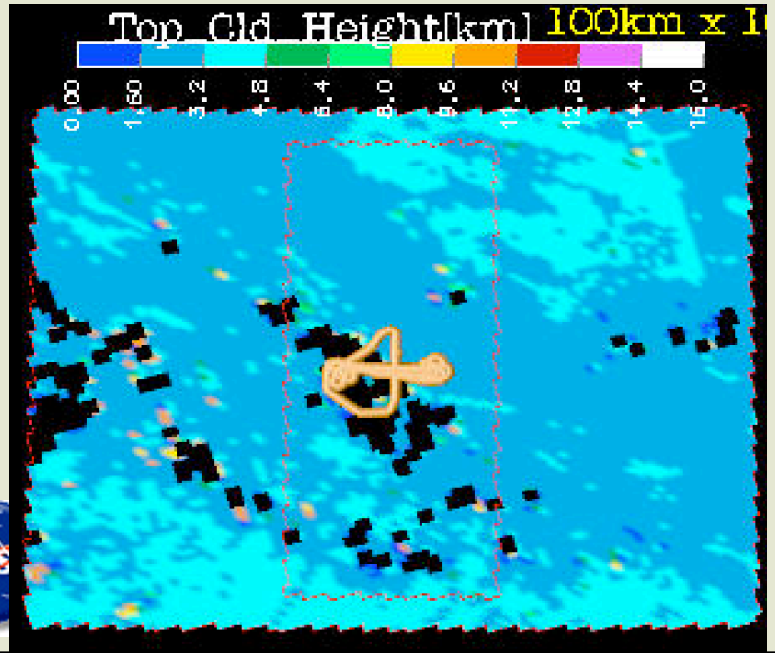
- **Some earlier VIRS & Terra MODIS results**
  - monthly mean parameters consistent to within expectations of sampling, spectral differences, r_e(VIRS) smaller due to 3.7-μm cal differences
  - SW fluxes computed with cloud results ~6 Wm^{-2} < CERES
  - LW fluxes computed with cloud results ~1 Wm^{-2} < CERES
  - mean stratus droplet sizes within 1 μm of surface values over ARM SGP
  - mean stratus OD within 4% of surface values over ARM SGP
  - most cloud heights within 1 km, daytime thin cirrus tends to bias low

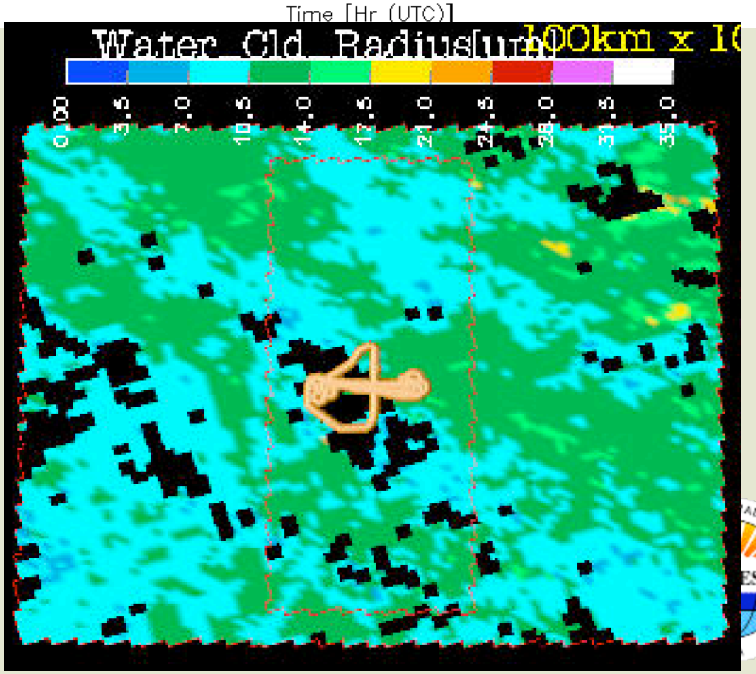
Flights over University of North Dakota, June 25, 2004

see Dong talk in CWG



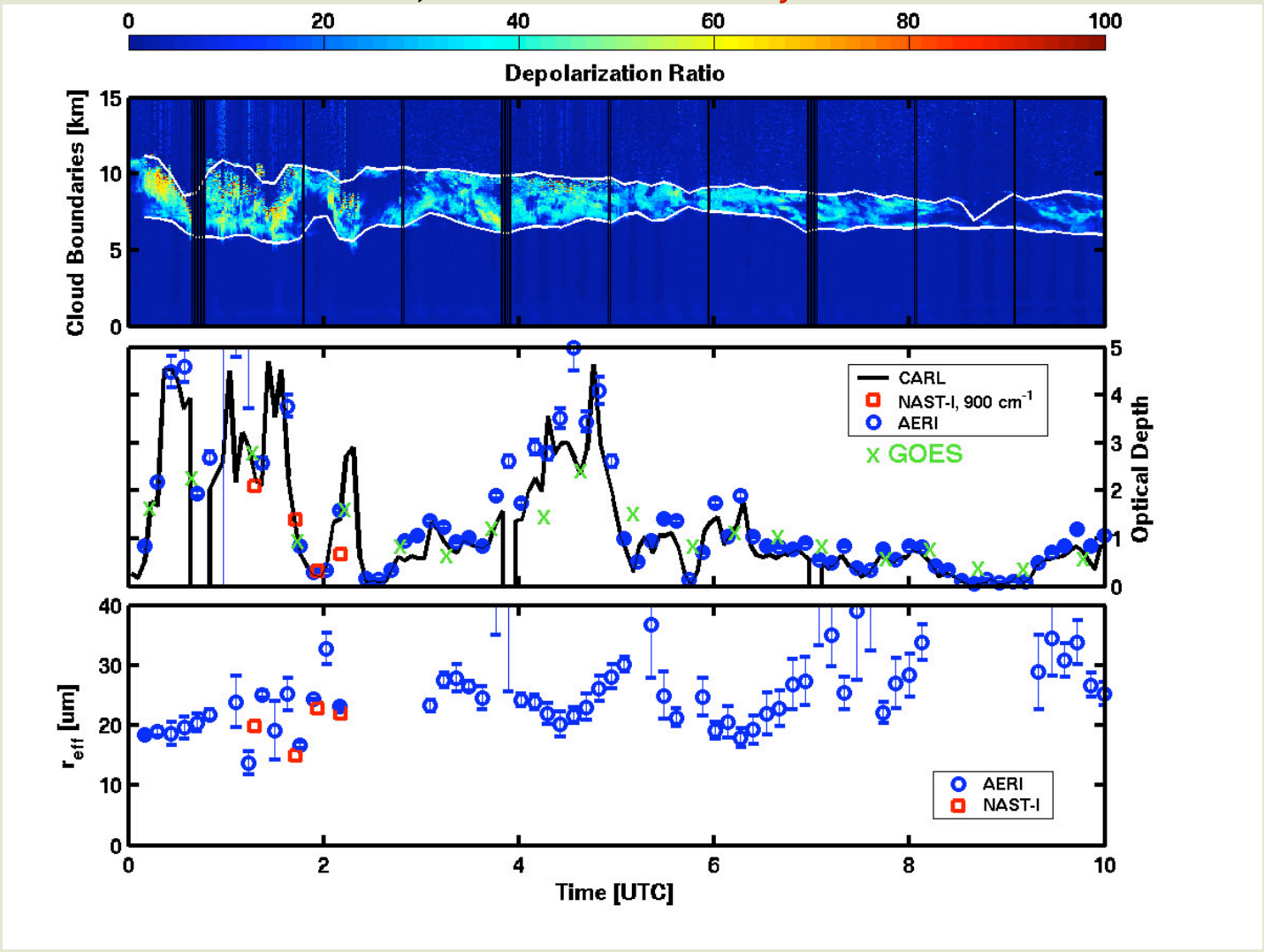






Comparison of GOES Optical Depth Retrievals at Night Over Texas with Retrievals from AERI & NAST-I on Proteus

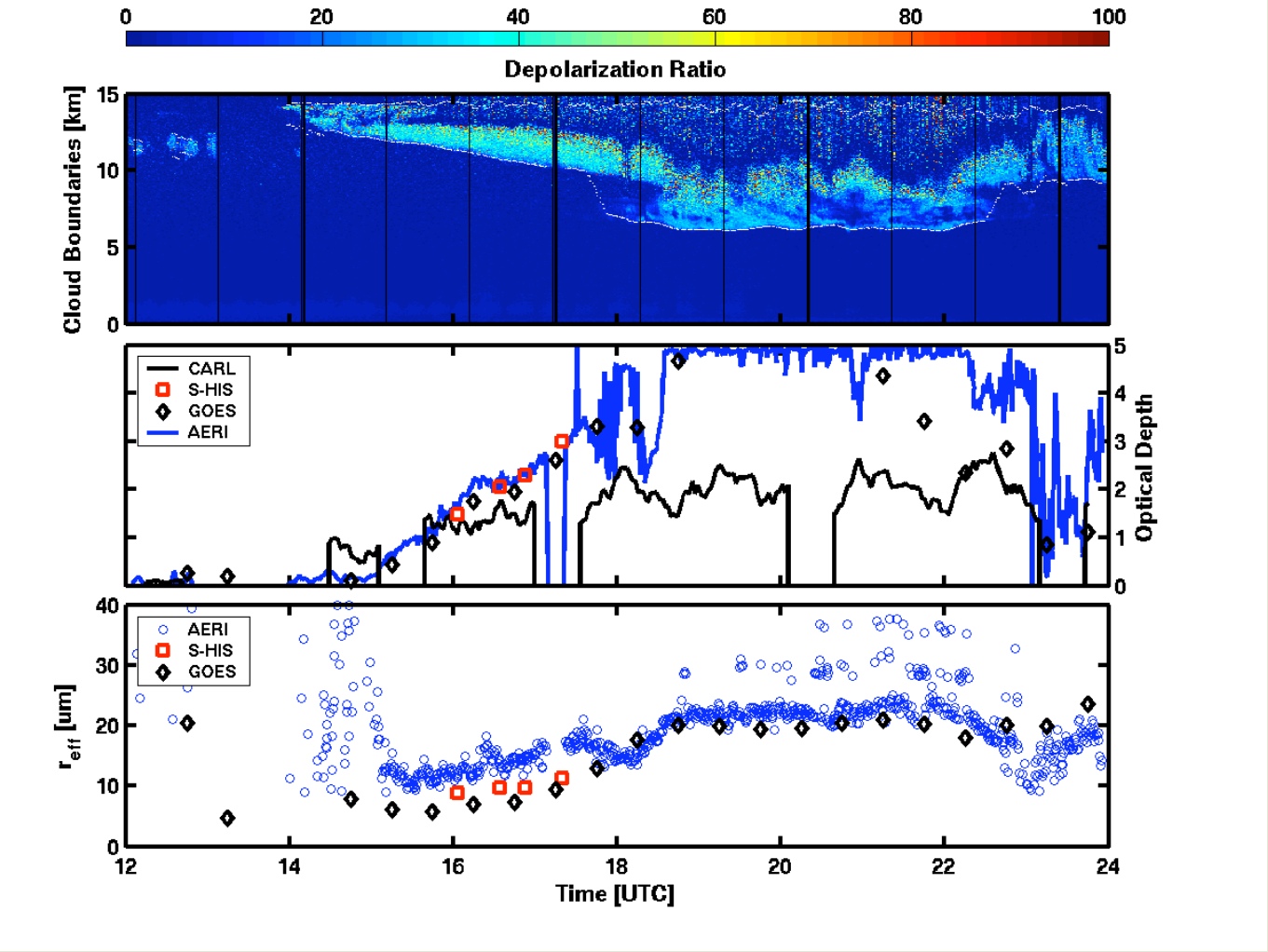
AFWEX, Nov 2004 *courtesy of Dan DeSlover*



Excellent agreement in optical depth

Comparison of GOES Daytime Cirrus Retrievals Over Texas with Retrievals from AERI & NAST-I on Proteus

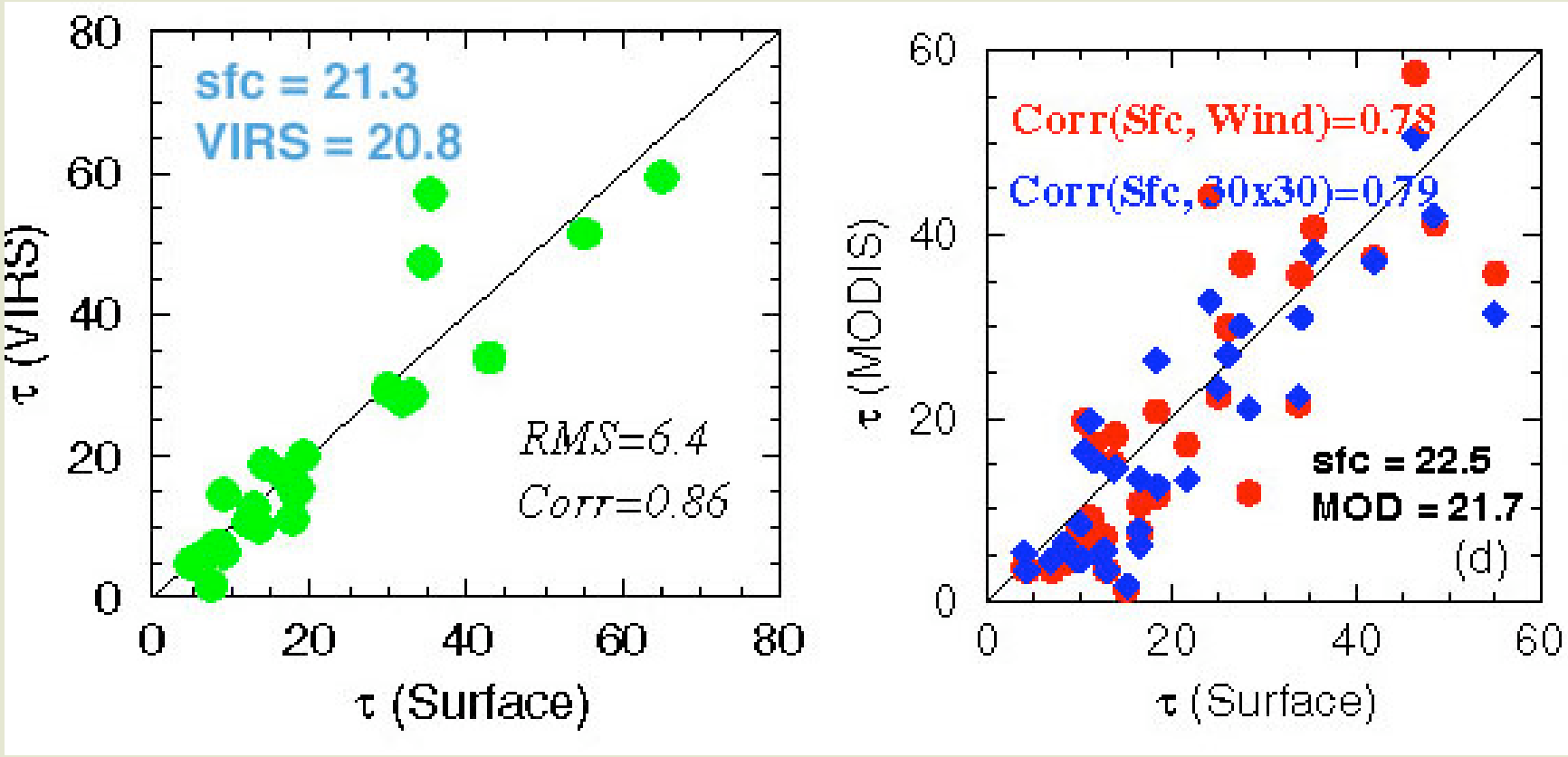
AFWEX, 24 Dec 2004 *courtesy of Dan DeSlover*



Excellent agreement in particle size and optical depth

Validation of CERES Cloud Optical Depth (Stratus)

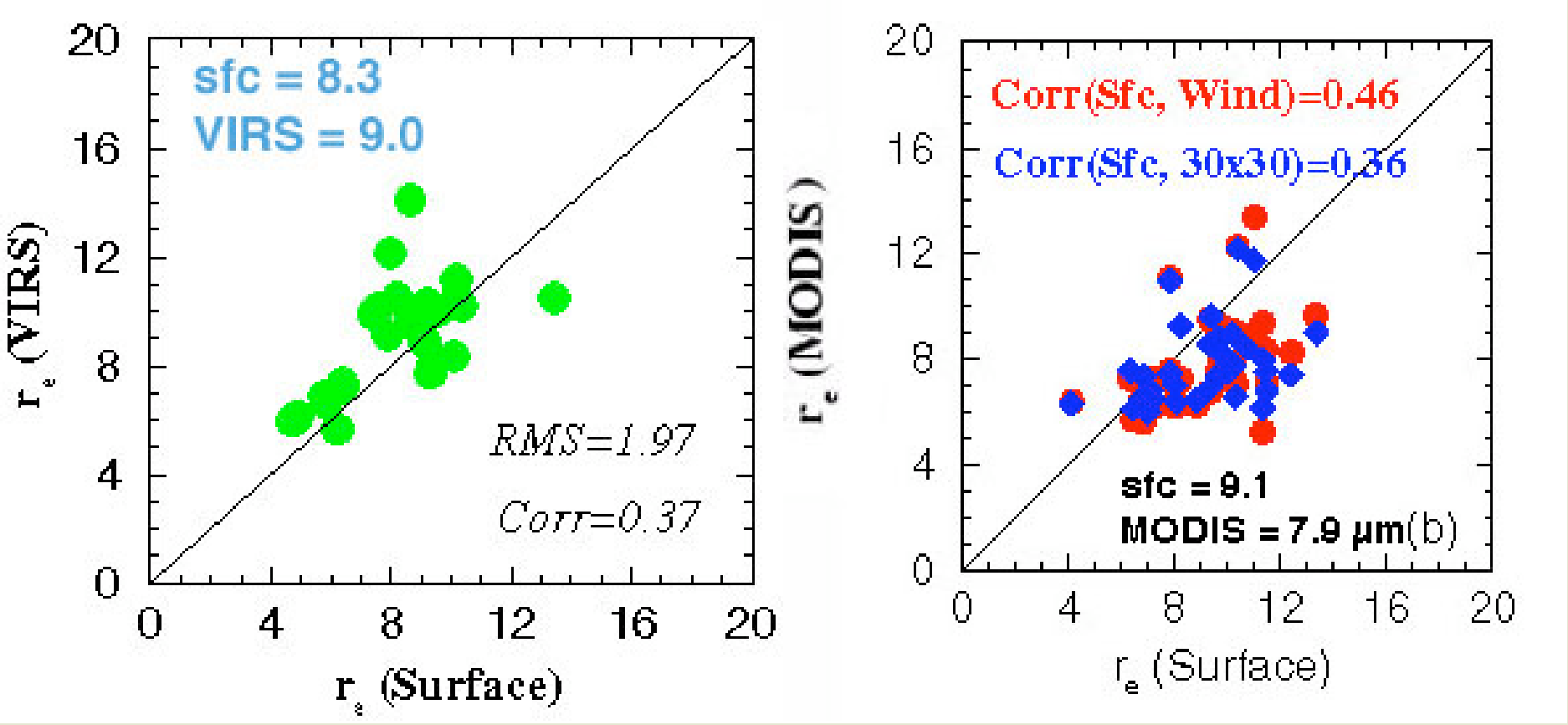
ARM SGP, VIRS 1998; MODIS 2000-2001



Excellent correspondence between CERES and surface-derived optical depths over ARM SGP site

Validation of CERES Cloud Droplet Size (Stratus)

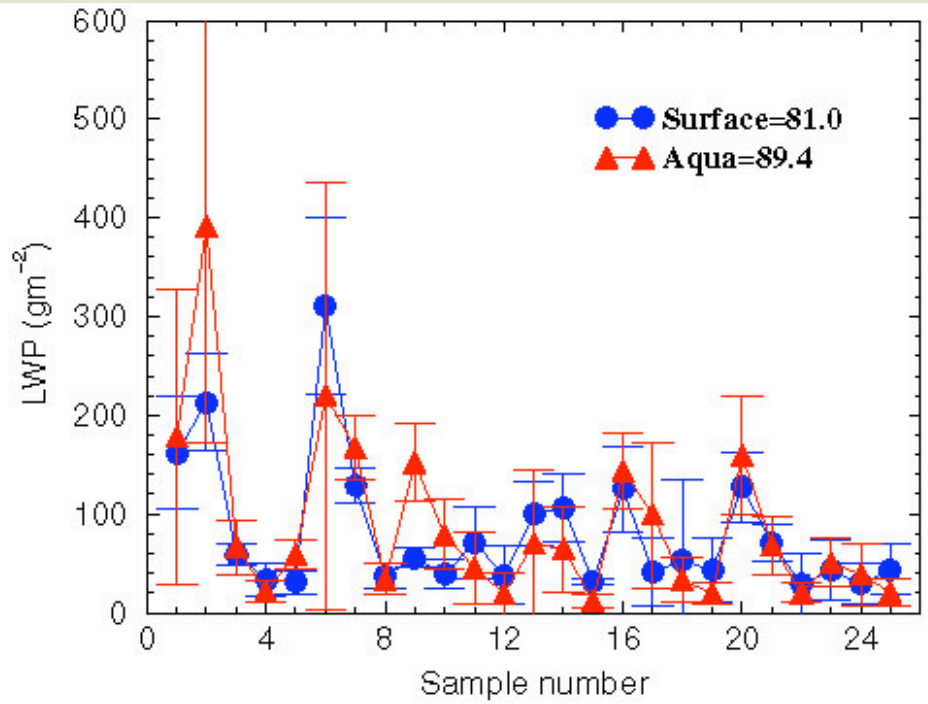
ARM SGP, VIRS 1998; MODIS 2000-2001

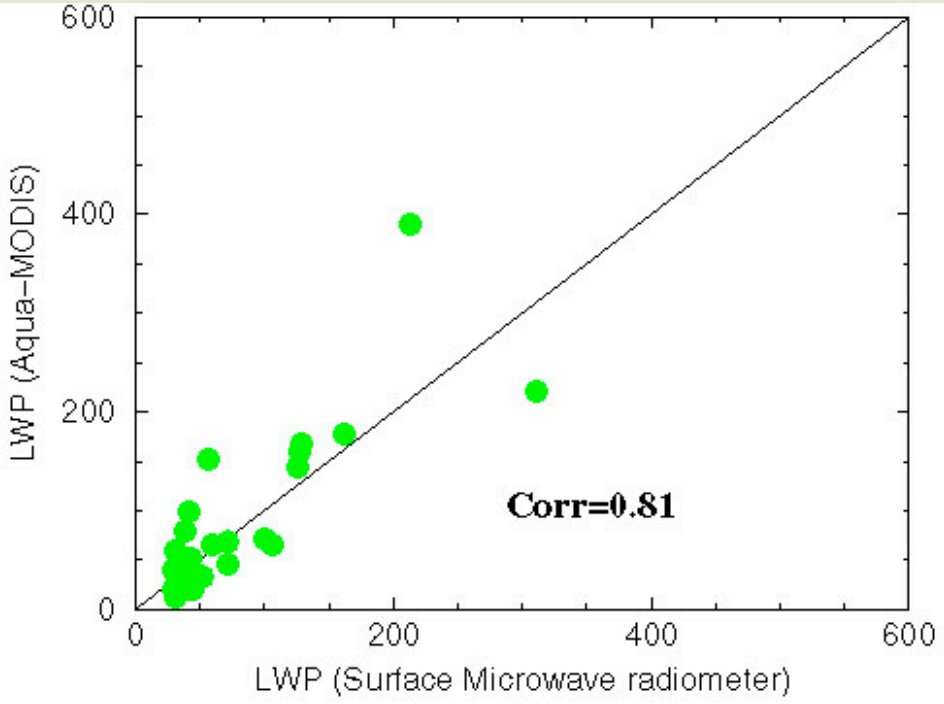


CERES average droplet sizes within ± 1 μm of surface-based values over ARM SGP site

Aqua Validation

Initial look at LWP over ARM SGP site, July 2002-Feb 2003





- **LWP:** VIRS + 16% ($r^2 = 0.96$)

  Terra - 18% ($r^2 = 0.88$)

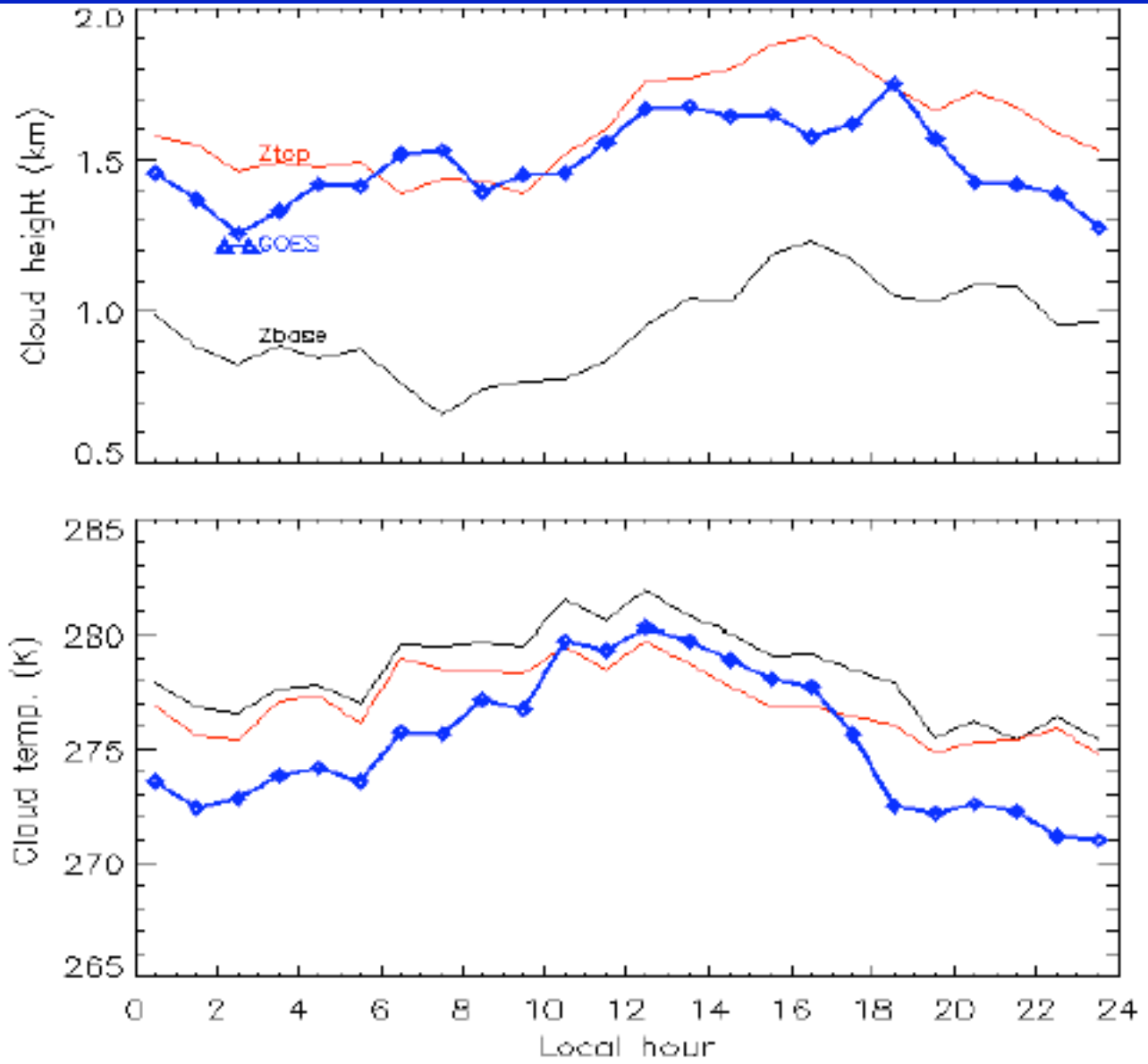
  Aqua + 10% ($r^2 = 0.81$)

Standard errors ~ 50%

Hourly Mean Stratus Cloud Heights at ARM SGP, 1997-2003

GOES as surrogate for MODIS

from Dong et al. III (2005)



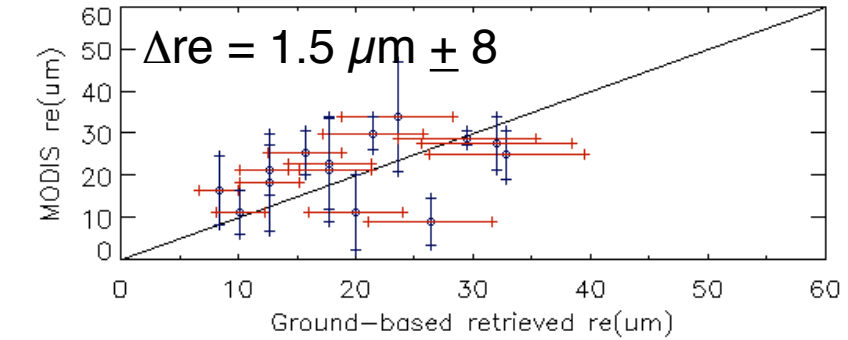
Boundaries from ARM MMCR + ceilometer

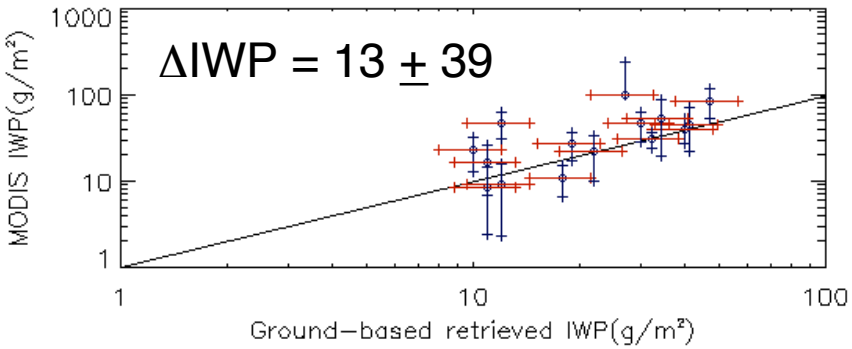
Radar - GOES: 0.1 km

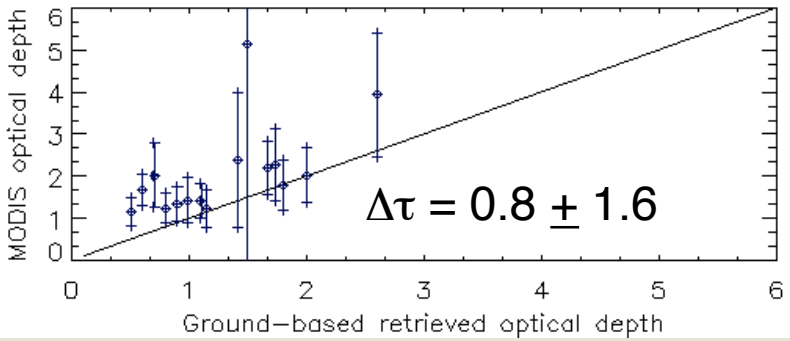
Greater radar temps may be due to sounding errors

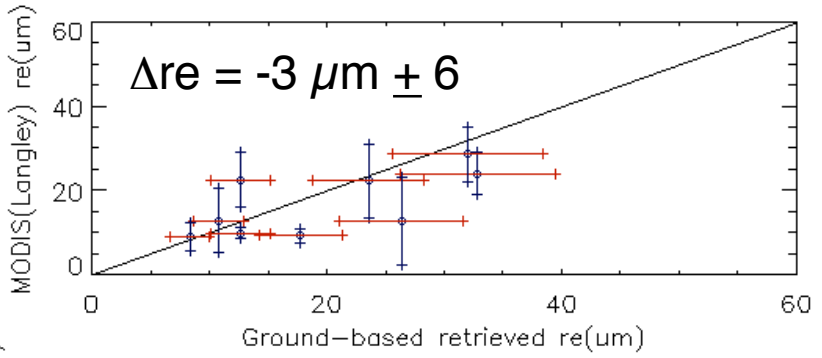
COMPARISON WITH SURFACE RADAR RETRIEVALS OF THIN CIRRUS

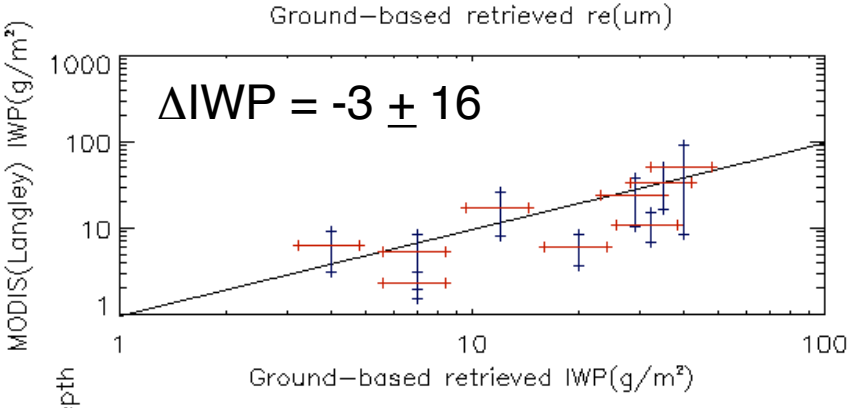
MOD06 **CERES**

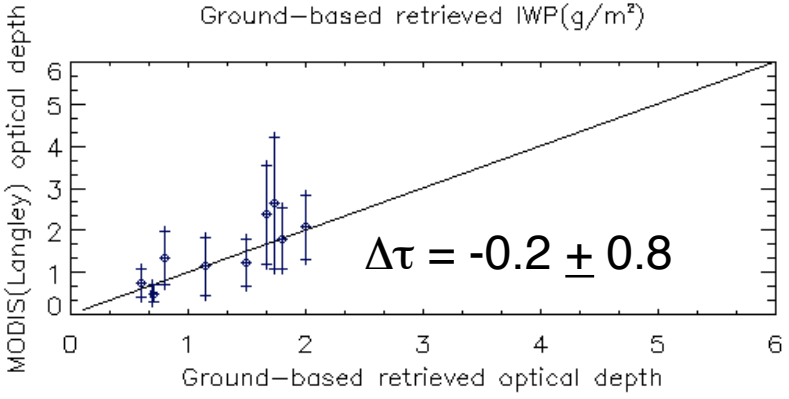








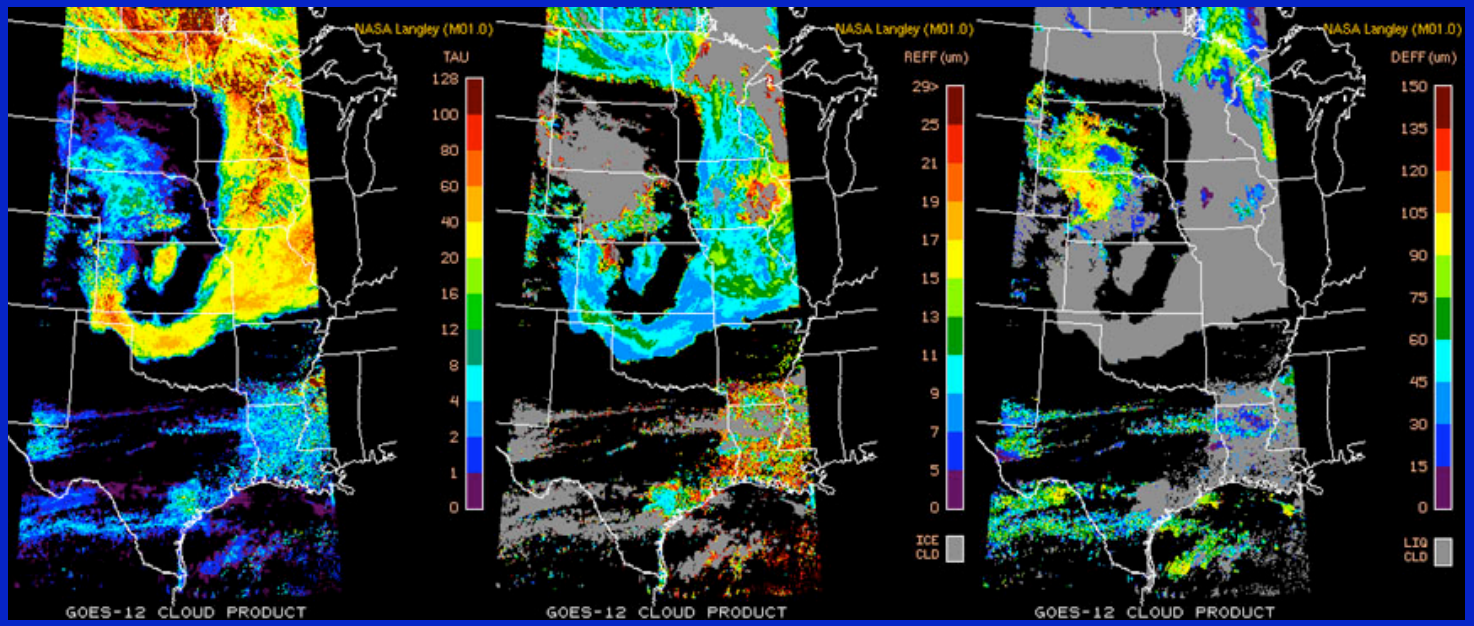




Over ARM SGP Central Facility, (see *Mace et al. 2005*)

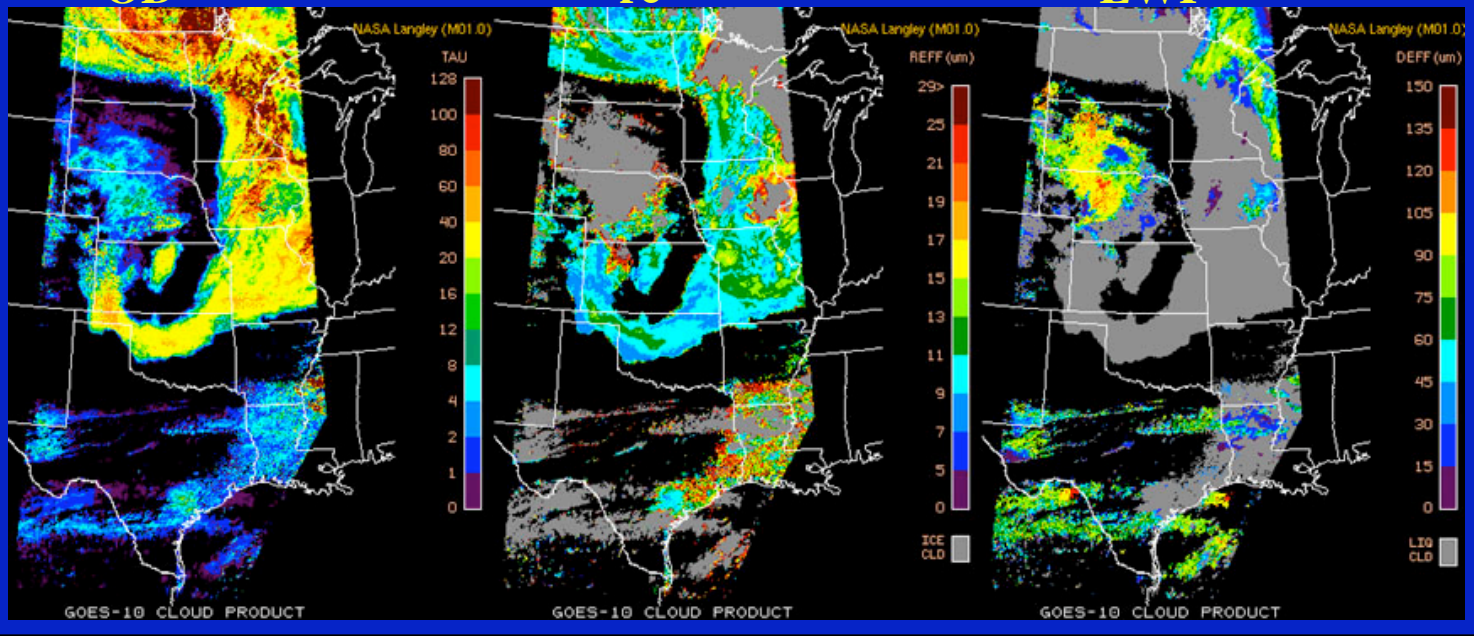
Comparison of Retrievals from Two Satellites, Dual Angle

Scattering angles change dramatically over the day: compare results for different views



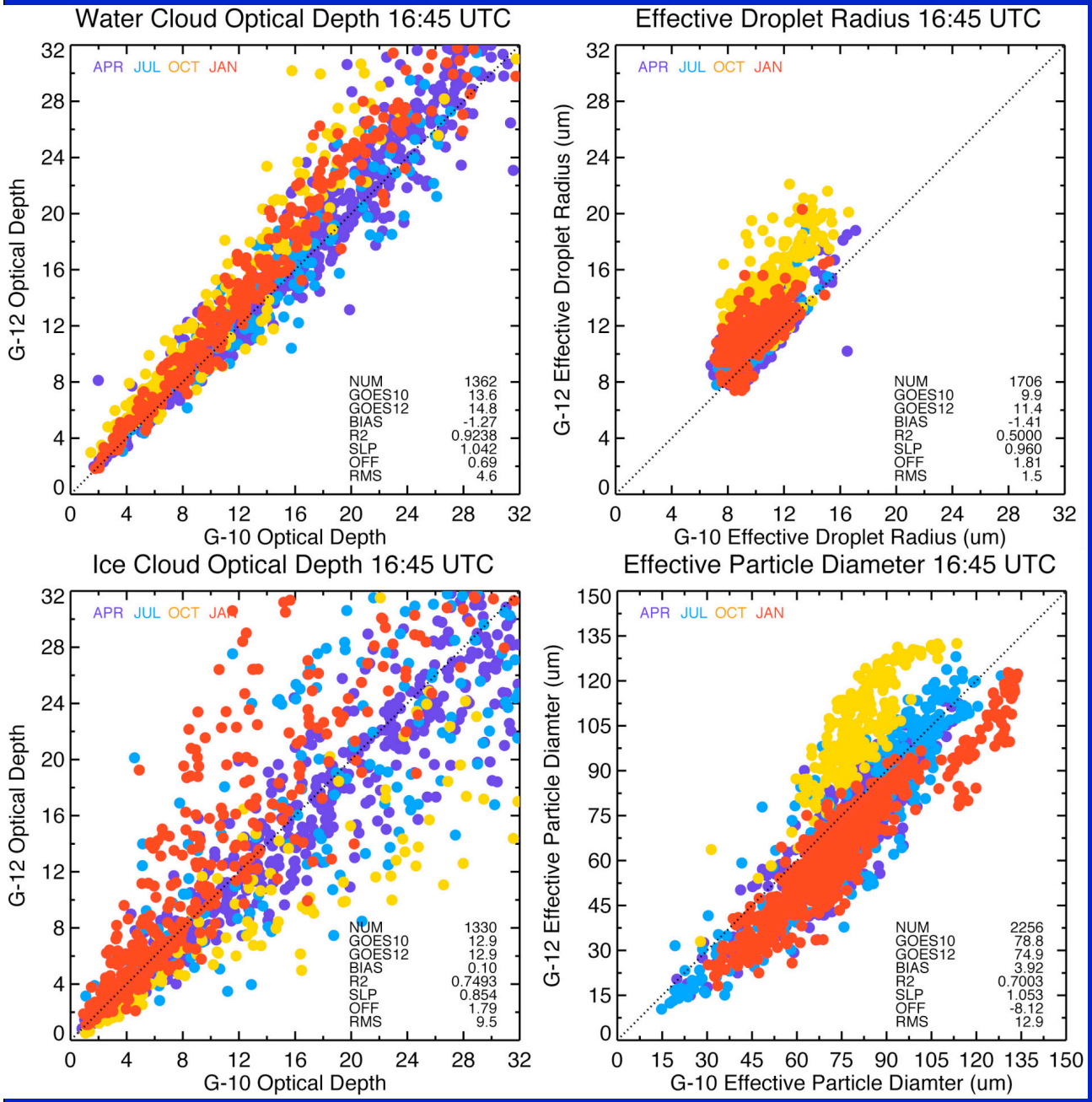
OD re LWP

GOES-12



GOES-10

Retrievals from Two Satellites, Dual Angle, 1645 UTC, 2004-05



Biases worst at certain angles, backscatter mainly

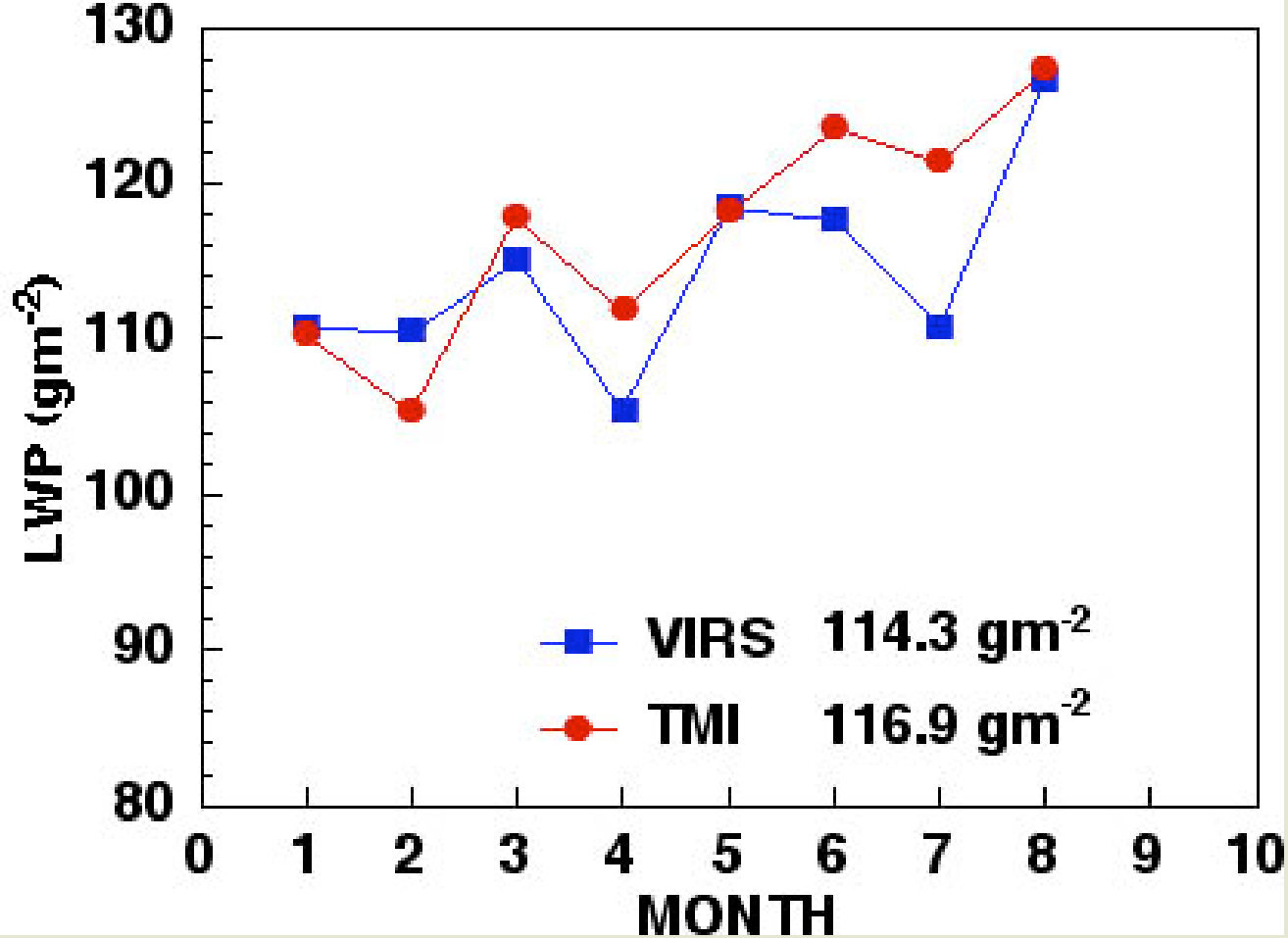
Mean differences for given pair of angles generally less than 10%, as high as 20%

Supercooled clouds might be the worst:

mixed phase?

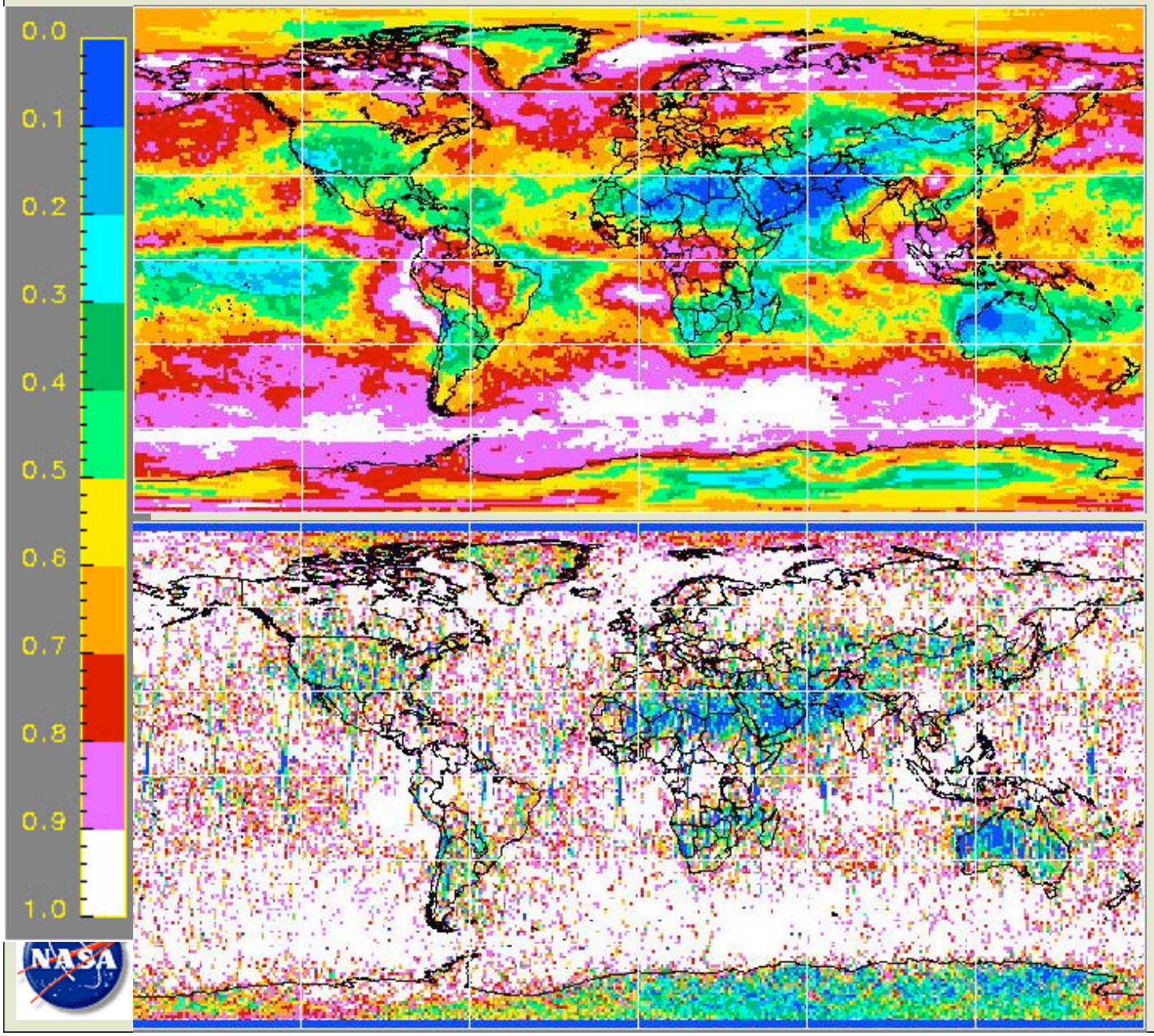
MONTHLY MEAN CLOUD LWP FROM VIRS & TMI OVER OCEANS

overcast, water cloud only, Tc > 273 K, SZA < 78°, no sunglint



TMI - TRMM Microwave Imager, LWP from method of *Lin et al., JGR, 1998*

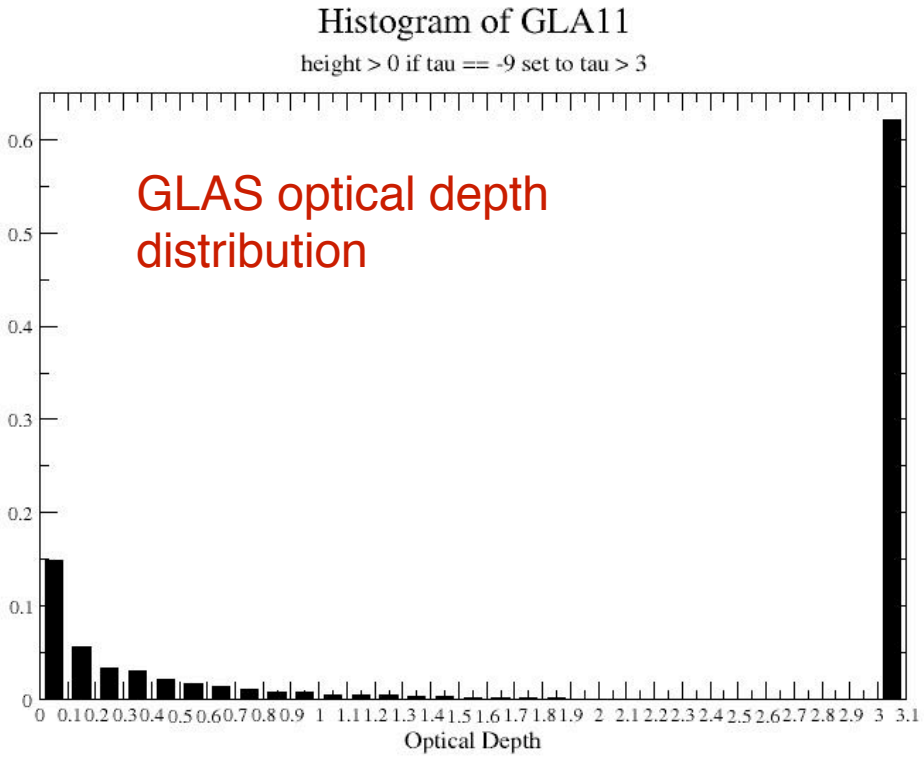
CERES Aqua MODIS vs GLAS Total Cloud Fraction, October 2003



Relative patterns similar, except for ocean where GLAS always sees clouds

GLAS sampling is weak

Antarctic patterns especially encouraging, validation data are rare



Why the big difference?

- Are there really thin clouds over the oceans nearly all the time?
- Are some aerosols mistaken for clouds by GLAS?

θ *CERES global cloud fraction = 0.612 (Fig. 5a)*

θ *GLAS global cloud fraction = 0.797 (Fig. 5b)*

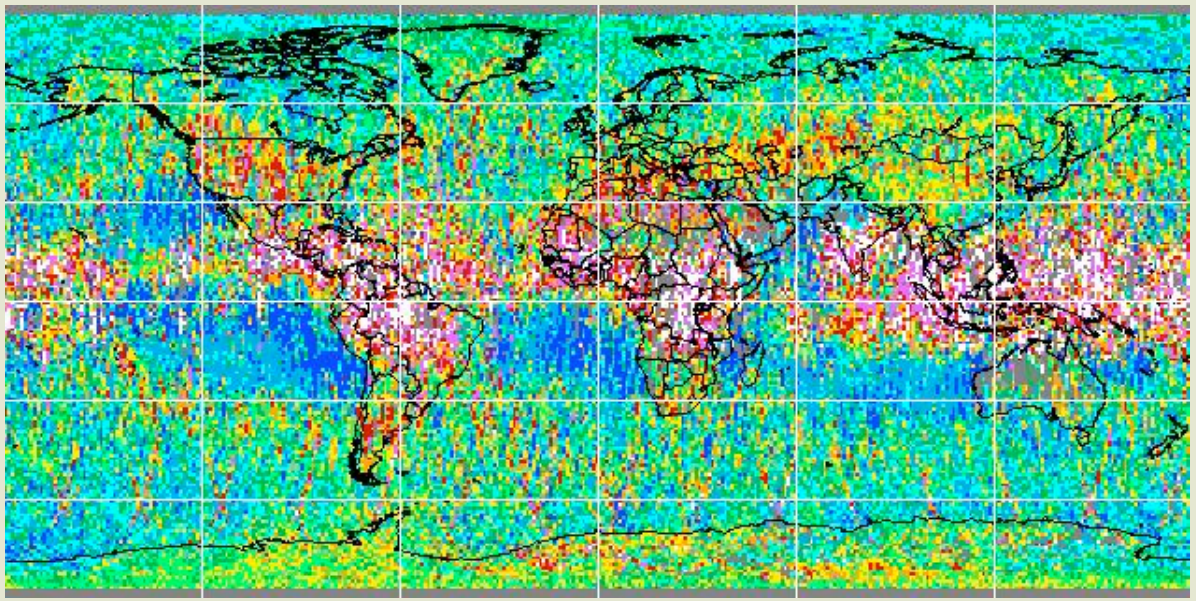
θ *GLAS thin cloud fraction = 0.180 (OD < 0.3)*

θ *CERES thin Cloud Fraction = 0.360 (OD < 3.0).* ◊

CERES misses nearly all clouds w/ OD < 0.3.

Comparison of CERES & GLAS Cloud Heights

Aqua, October 2003

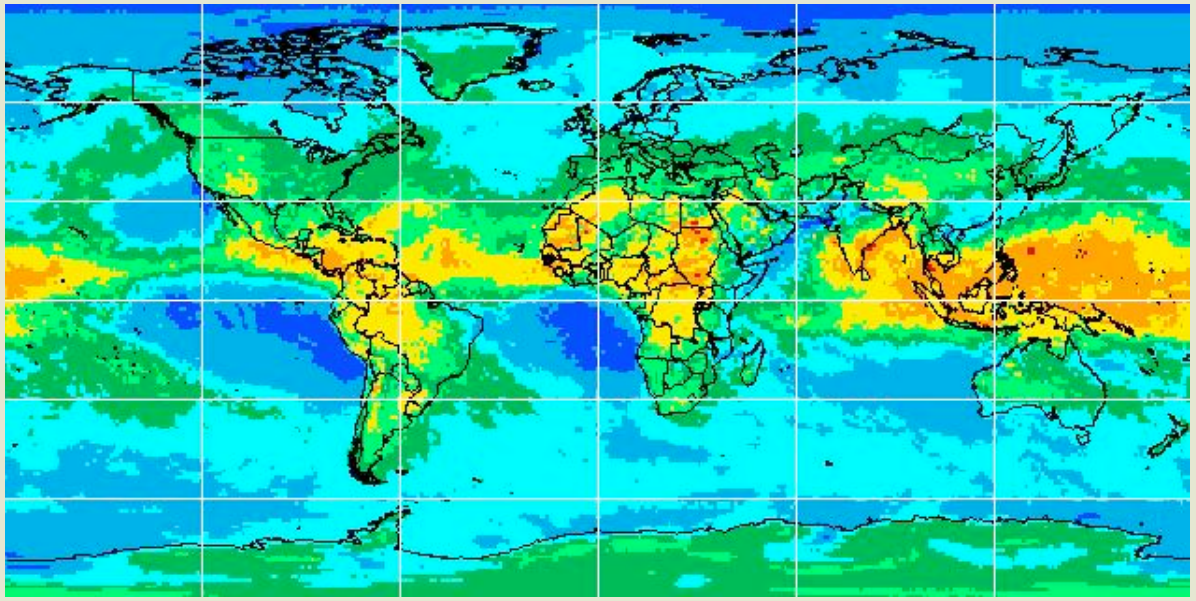


GLAS uppermost cloud height

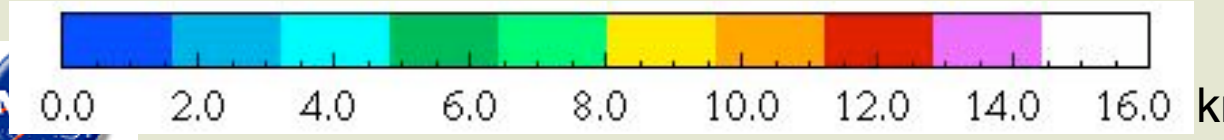
Cirrus is not ubiquitous

-red, white, & gold not seen over all oceans

- some thin clouds = aerosols

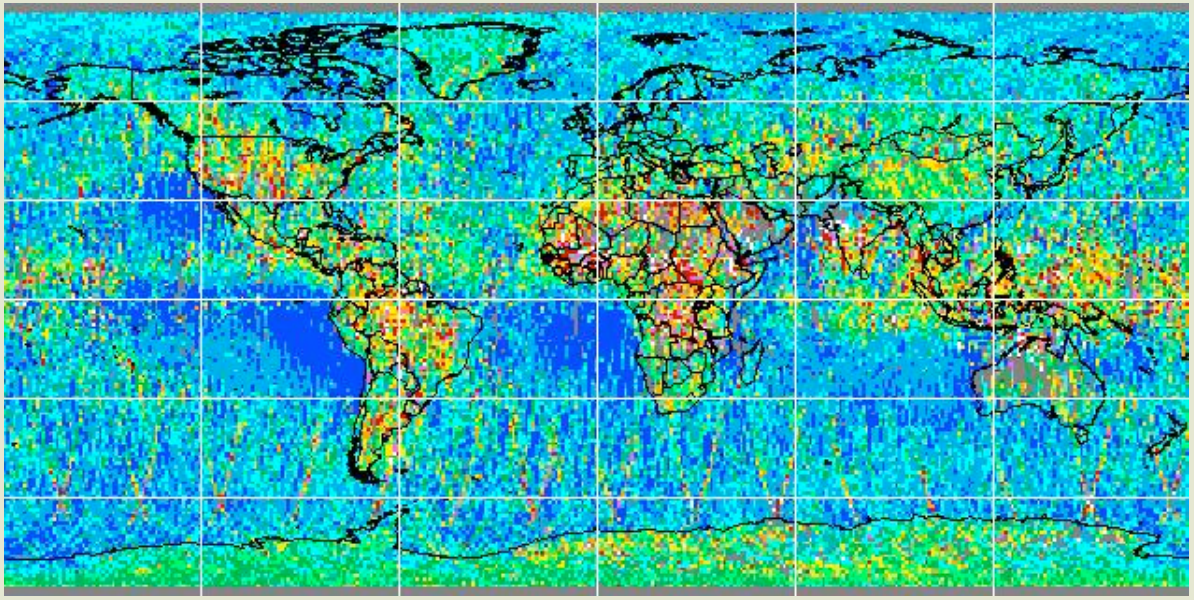


CERES average effective cloud height

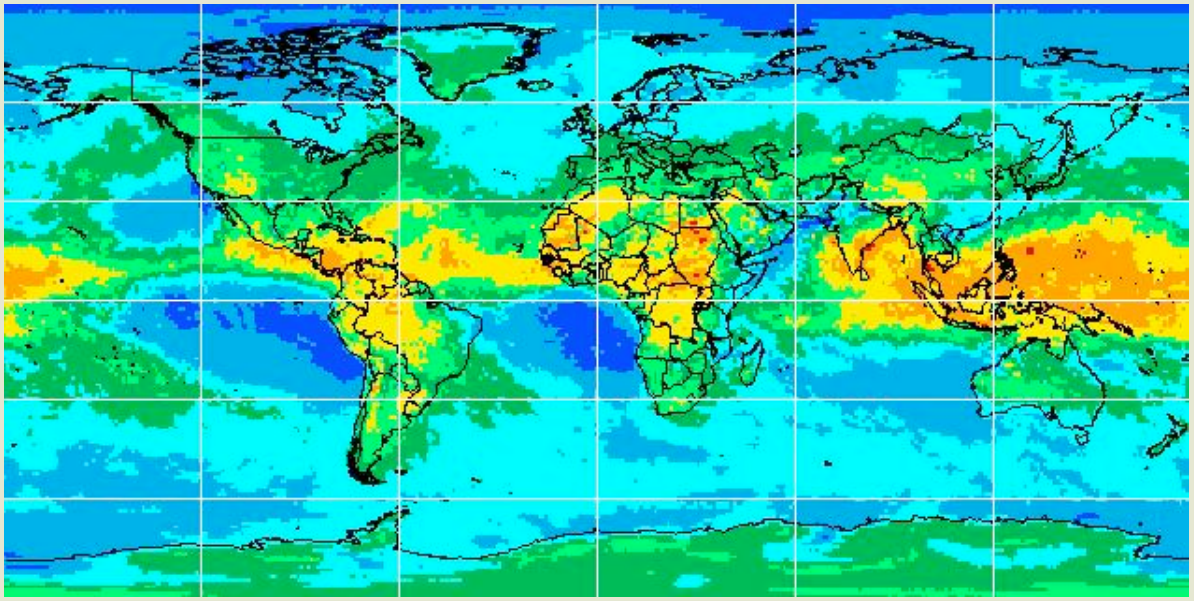


Comparison of CERES & GLAS Cloud Heights

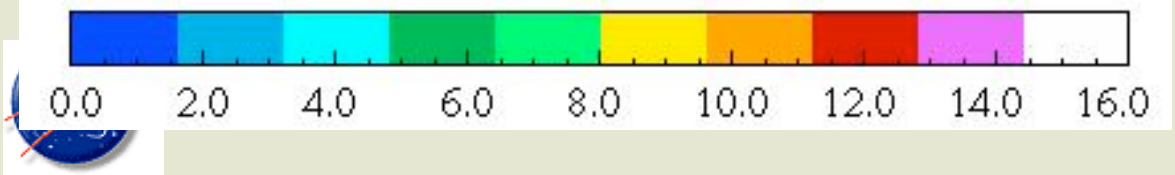
Aqua, October 2003



GLAS lowermost cloud height



CERES average effective cloud height



km

CERES vs. GLAS Cloud Height Summary

¬ ***Global Average = 7.31 km (GLAS)***
(Top Cloud Height for ALL Clouds)

¬ ***Global Average = 4.23km (GLAS)***
(Top Cloud Height for single layer clouds and bottom layer clouds for overlapped clouds)

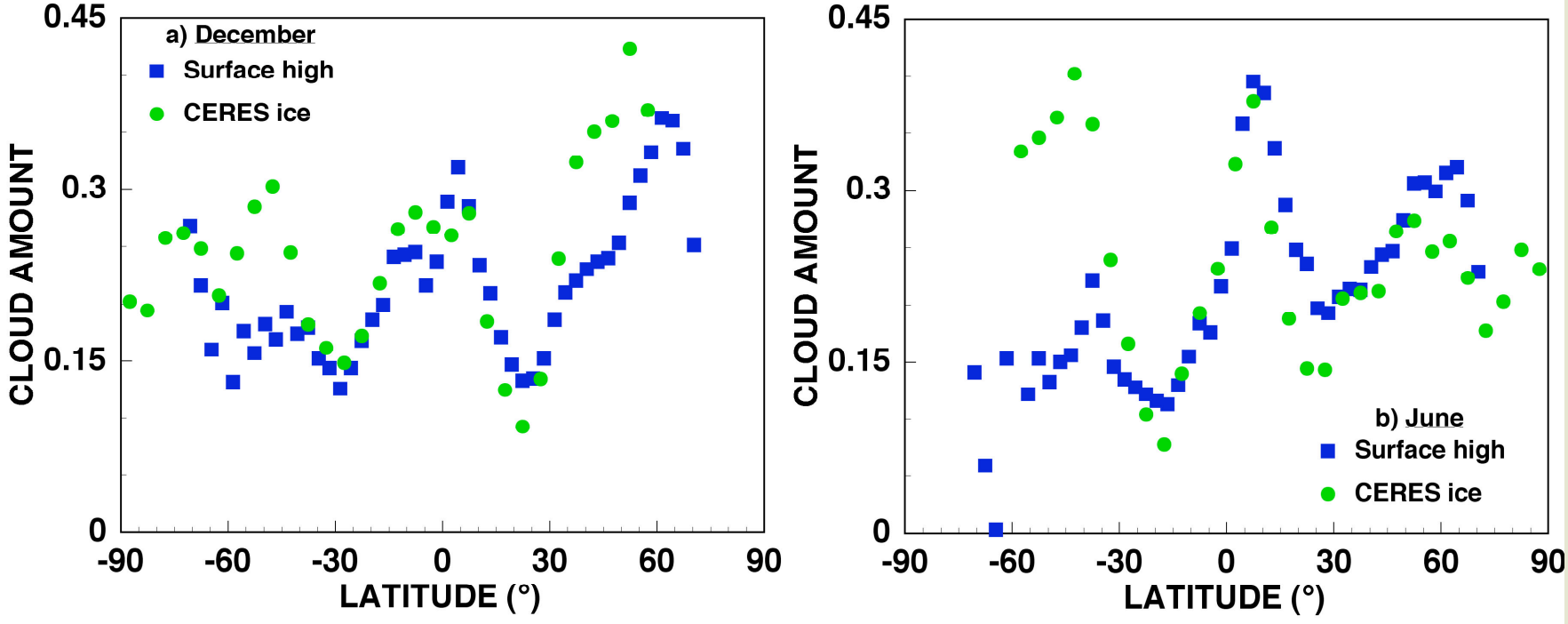
¬ ***Global Average = 5.22 km (CERES)***
(Effective Cloud Height assuming all clouds are single clouds).

- CERES heights between average for lowest and highest GLAS cloud-tops
  - *GLAS sees through clouds with OD < 2*
  - *overlapped cloud method should improve comparison*
- CERES characterization of stratus regimes very similar to GLAS
- CERES heights over land too low? patterns OK
- CERES high cloud patterns very similar to uppermost clouds,but low
  - *lack of cirrus everywhere suggests GLAS detecting many low thin clouds or aerosols*

COMPARISONS WITH OTHER DATASETS

- SURFACE CLIMATOLOGY
- ISCCP
- MODIS Team Results

COMPARISON OF CERES TERRA MODIS ICE AND SURFACE HIGH CLOUD AMOUNTS, 2000

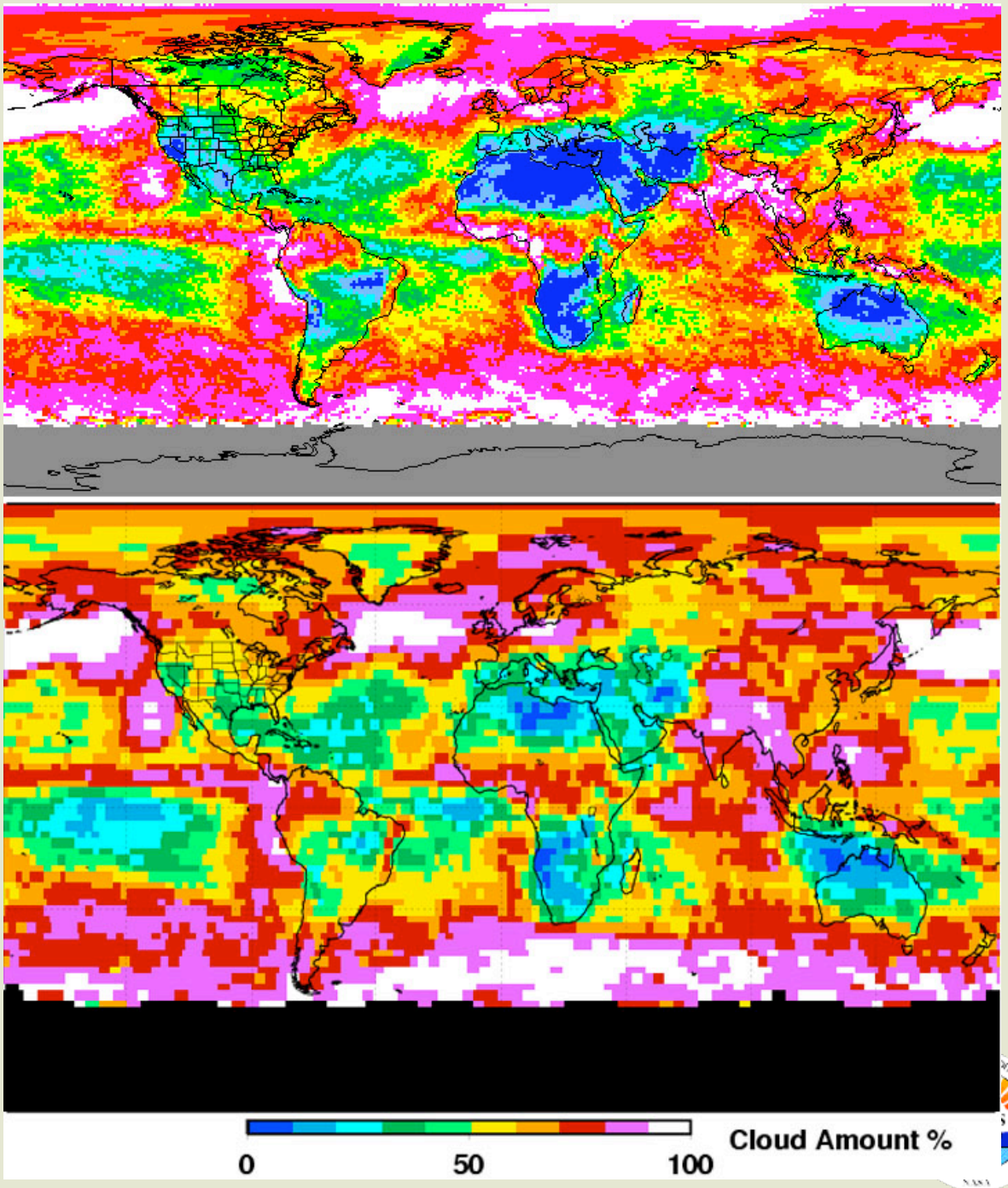


Differences in southern midlatitudes possibly due to lack of observations from surface or to lower altitude of ice clouds

CERES day

CERES vs ISCCP Cloud Amount Jul. 2000

ISCCP mean



Monthly mean cloud fractions from surface, ISCCP, and CERES Terra MODIS

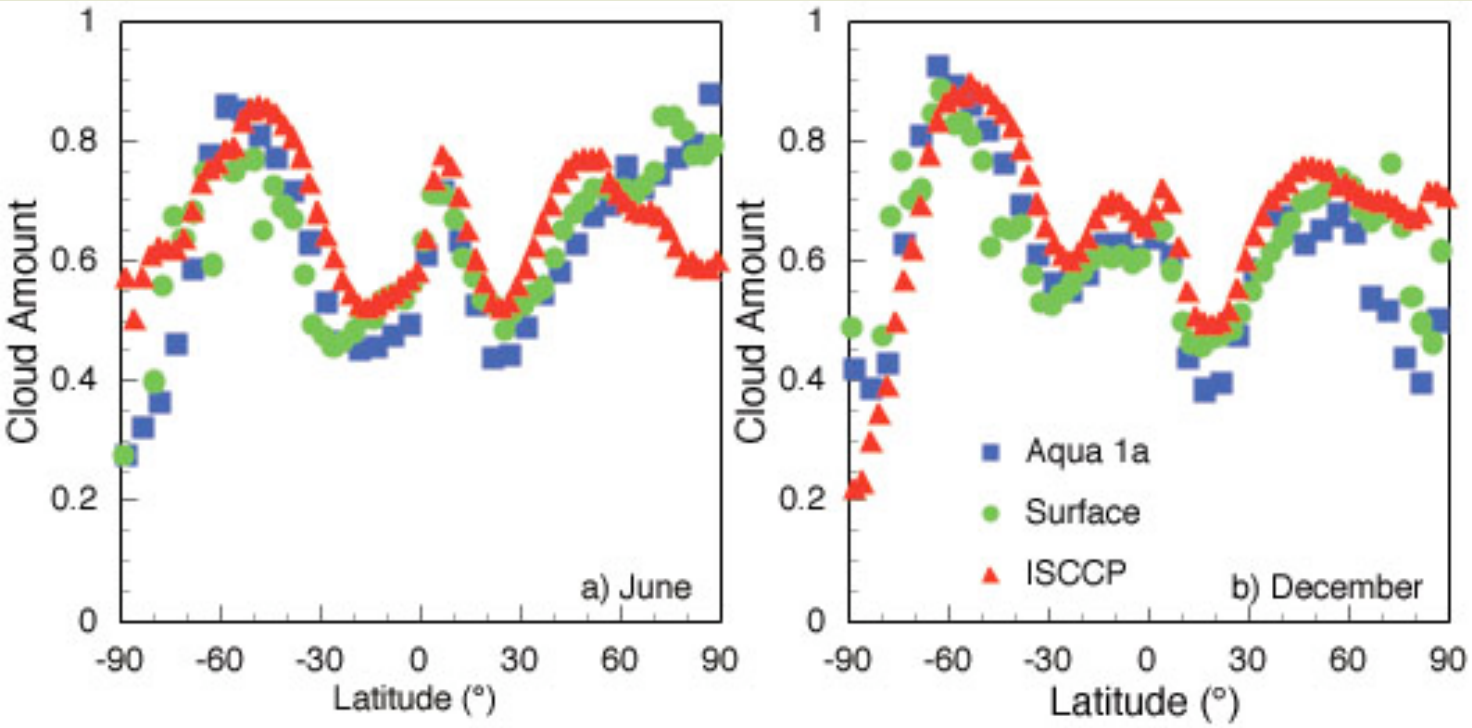
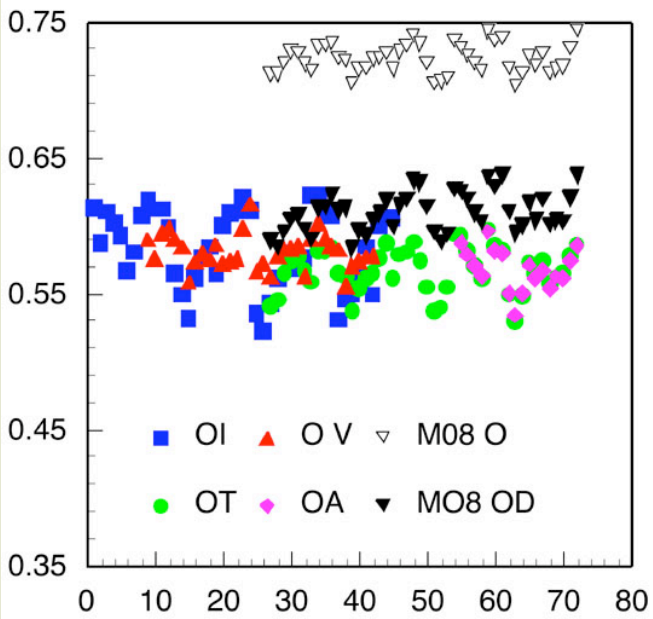


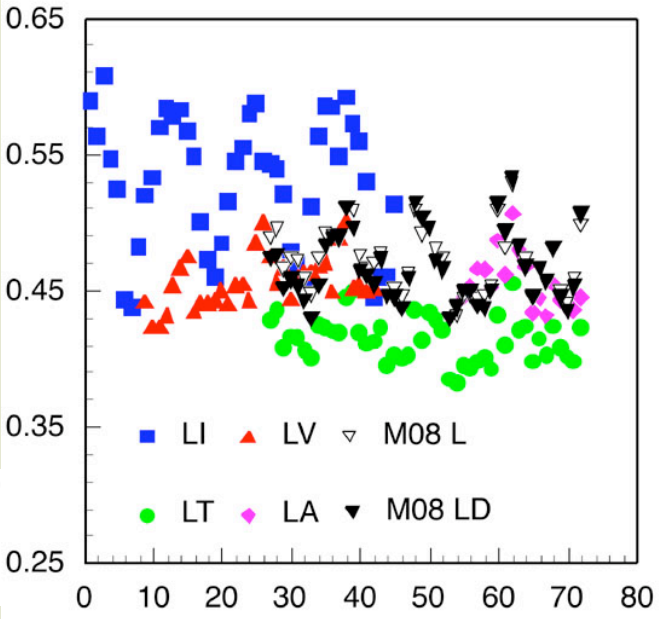
Table 1. Monthly mean cloud amounts in percent from surface observations (Hahn and Warren, 1999), CERES, and ISCCP (Rossow and Schiffer, 1999).

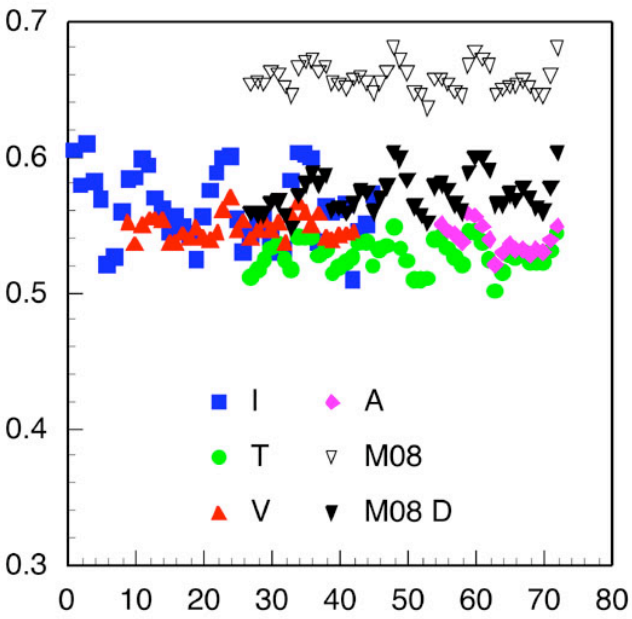
Domain	Surface (1971-96)	*Terra* MODIS Ed 2 12/2002, 6/2003	*Aqua* MODIS Ed 1a 12/2002, 6/2003	ISCCP D2 (1984-98)
60°S - 60°N, December	60.9	60.3	61.2	68.2
90°S - 90°N, December	61.9	60.6	61.4	68.2
60°S - 60°N, June	58.6	58.6	58.9	66.6
90°S - 90°N, June	60.0	60.3	59.8	66.6

Total cloud amount comparison from 1998-2001 37N-37S

Cloud Amount







Time in months since December 1997

O = Ocean

L = Land

D - Daytime

I - ISCCP

T - Terra CERES

A - Aqua CERES

V - VIRS

M08- MOD08

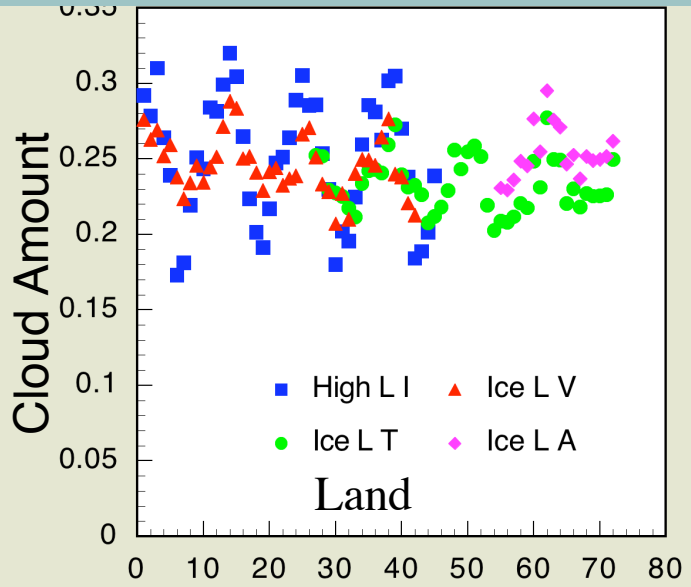
Ice/High cloud amount Comparison from 1998-2001 37N-37S

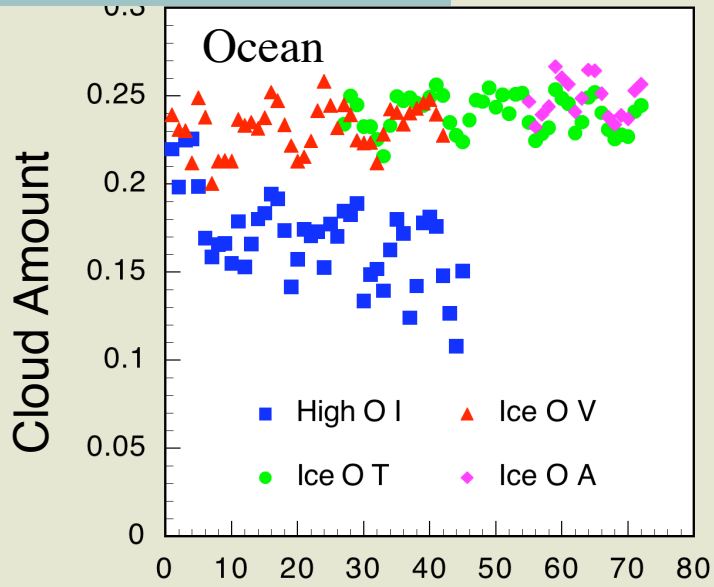
I - ISCCP

T - Terra CERES

A - Aqua CERES

V - VIRS



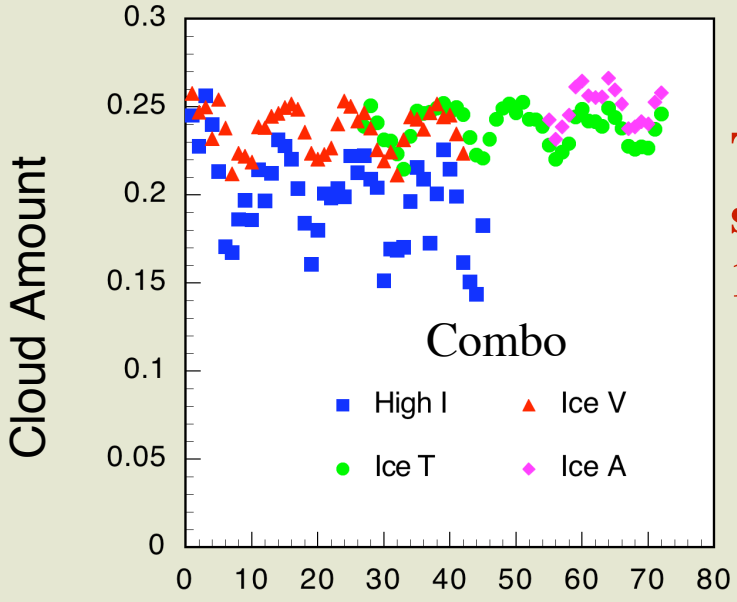


Good agreement in magnitude over land

Divergent trends over ocean:

ISCCP shows significant drop

All CERES consistent



Time in months since December 1997

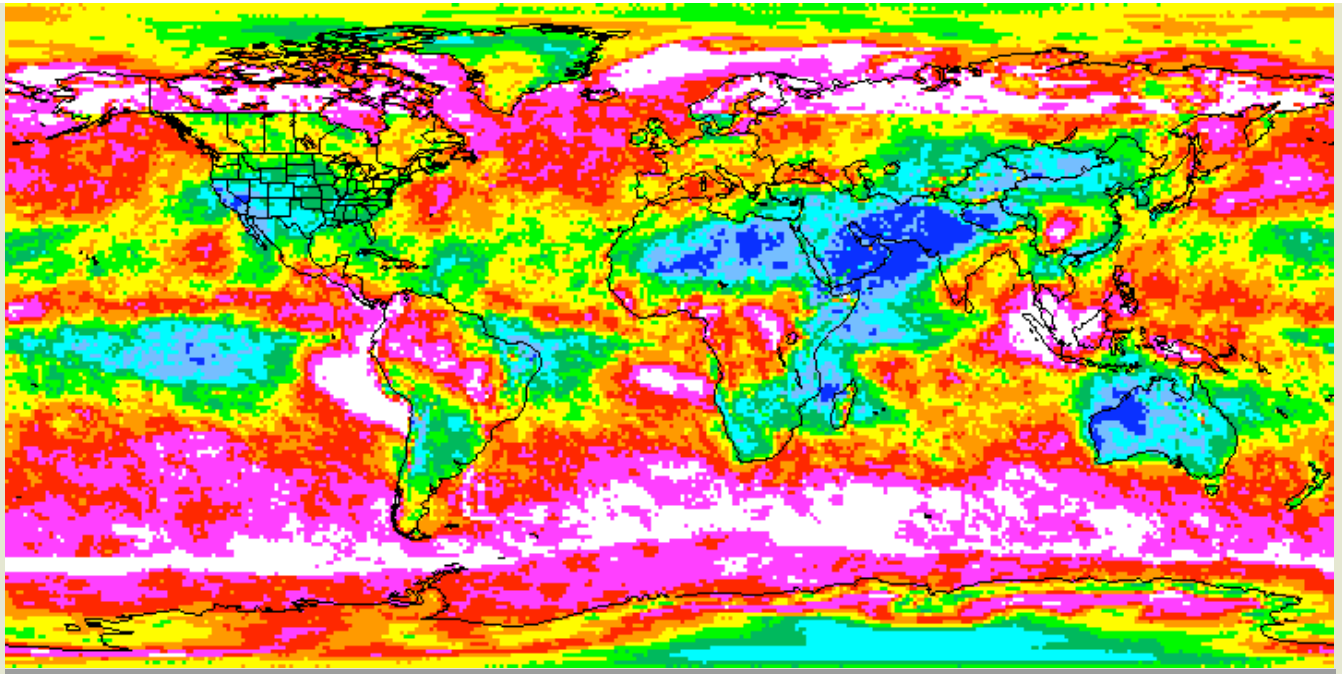
CERES MODIS CLOUD PRODUCTS ARE DIFFERENT THAN THE MODIS TEAM PRODUCTS

- Different masks (use different channels, thresholds, etc.)
- Different radiative transfer
  - different ice/water models
  - different atmospheric properties
  - different interpretive models
- Different processing systems

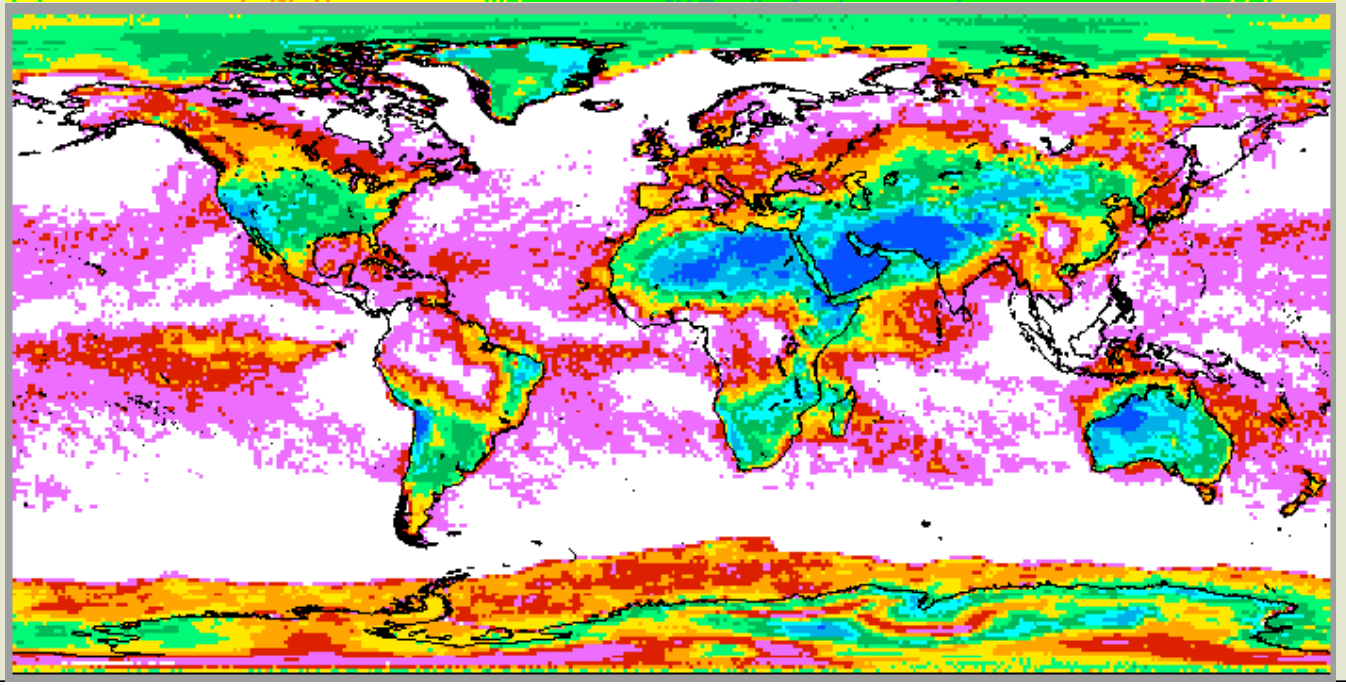
=> differences in products

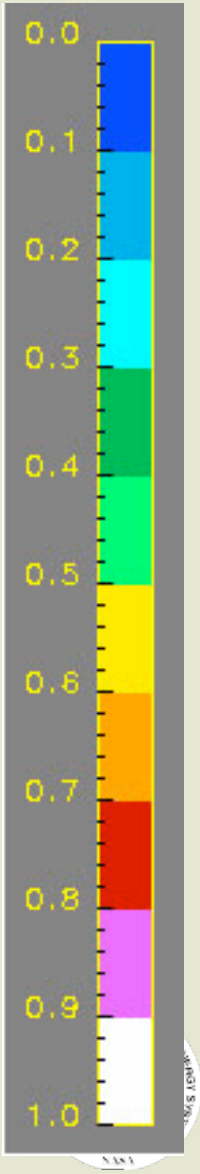
NIGHT CLOUD AMOUNTS, *Terra*, October 2003

CERES Ed2



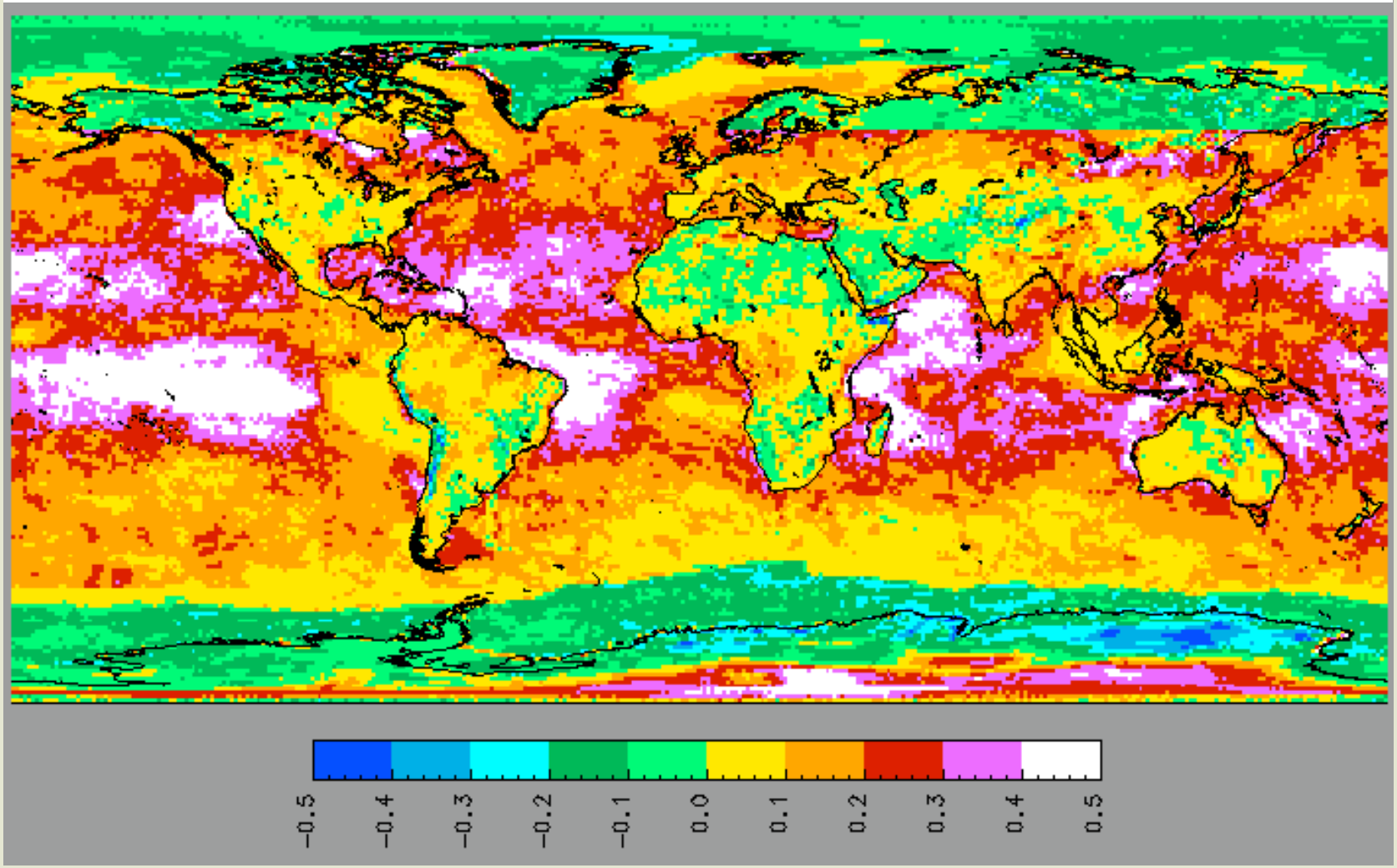
MOD08
MODIS Team





NIGHTTIME CLOUD AMOUNT DIFFERENCE, MOD08 - CERES

Terra, October 2003



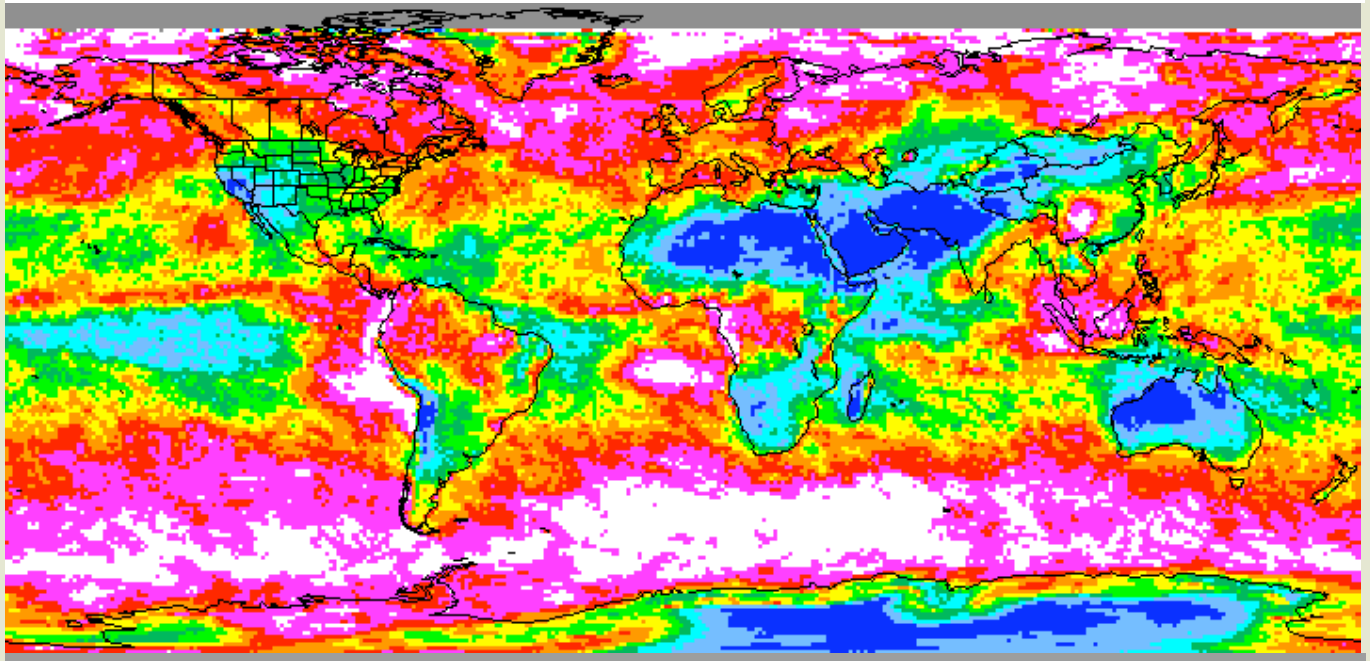
CERES fewer clouds over oceans & tropical land

more clouds in polar regions

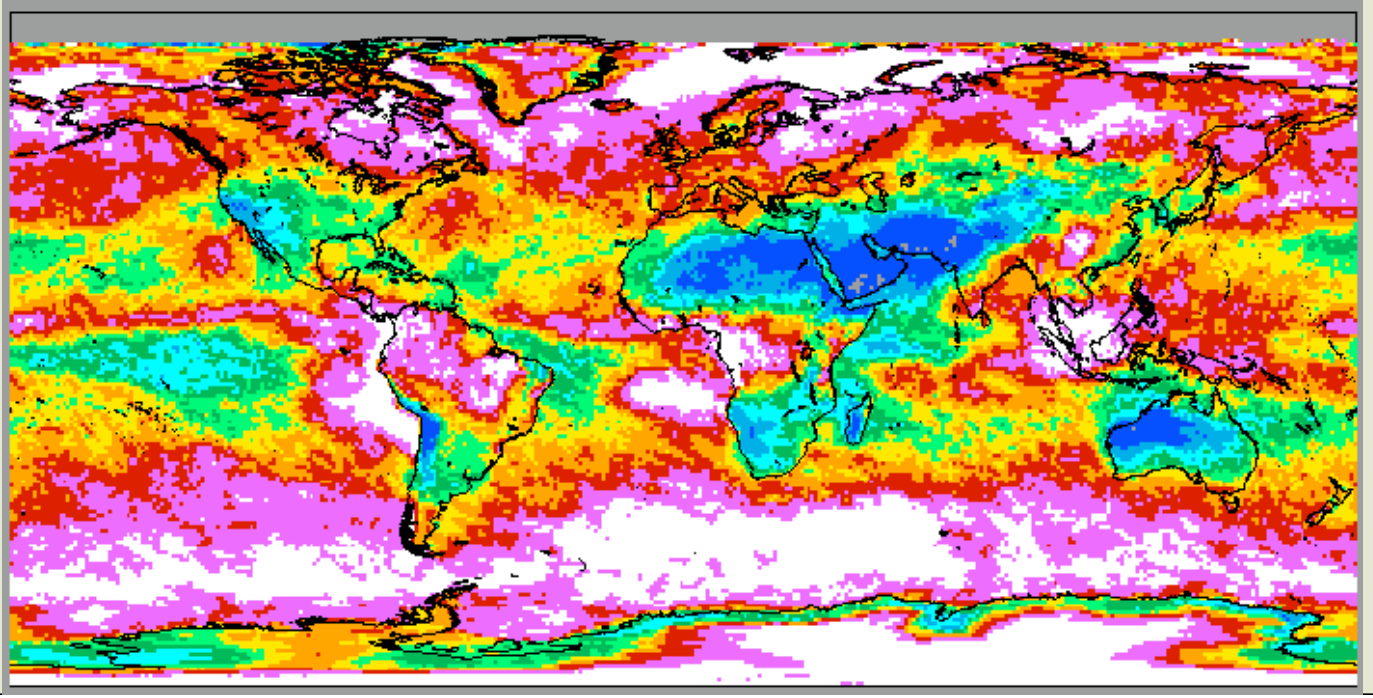
MOD08 night cloud amount ~0.2 > CERES

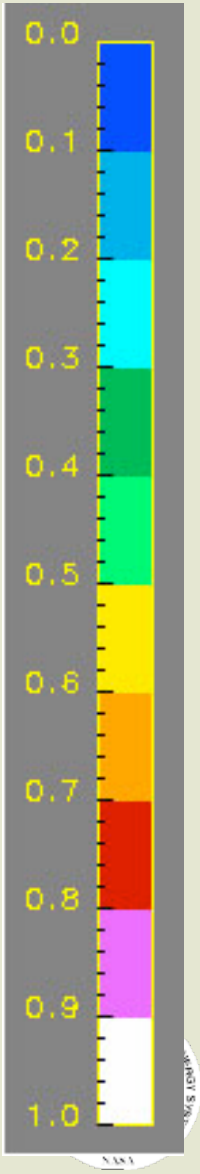
DAYTIME CLOUD AMOUNTS, *Terra*, October 2003

CERES Ed2



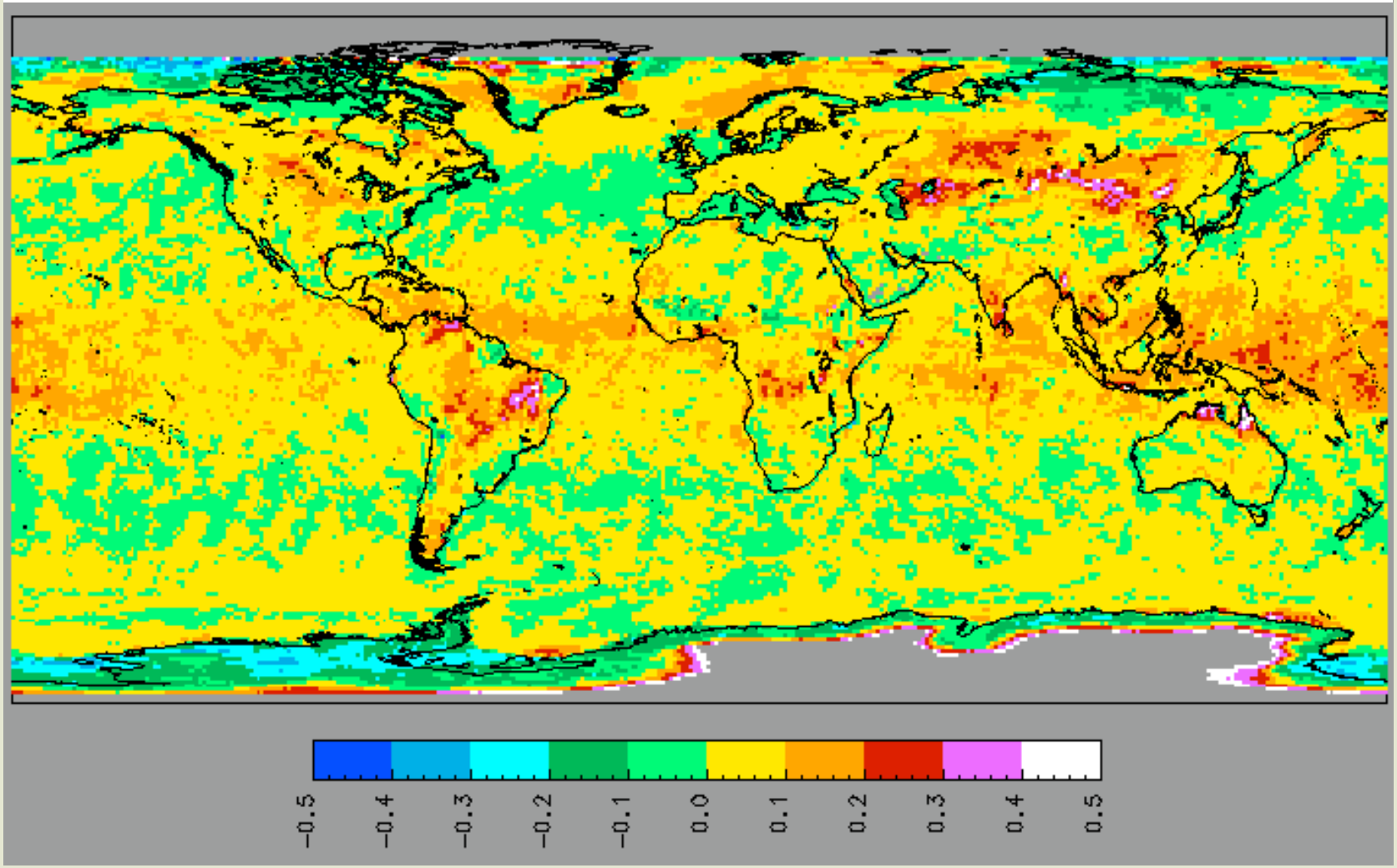
MOD08
MODIS Team





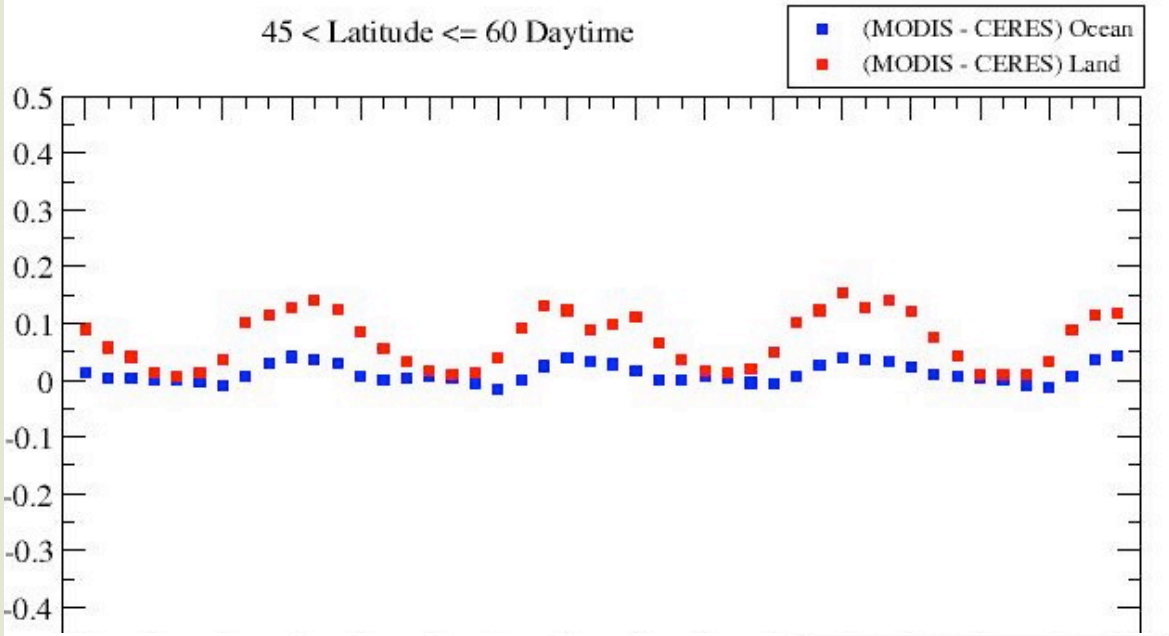
DAYTIME CLOUD AMOUNT DIFFERENCE, MOD08 - CERES

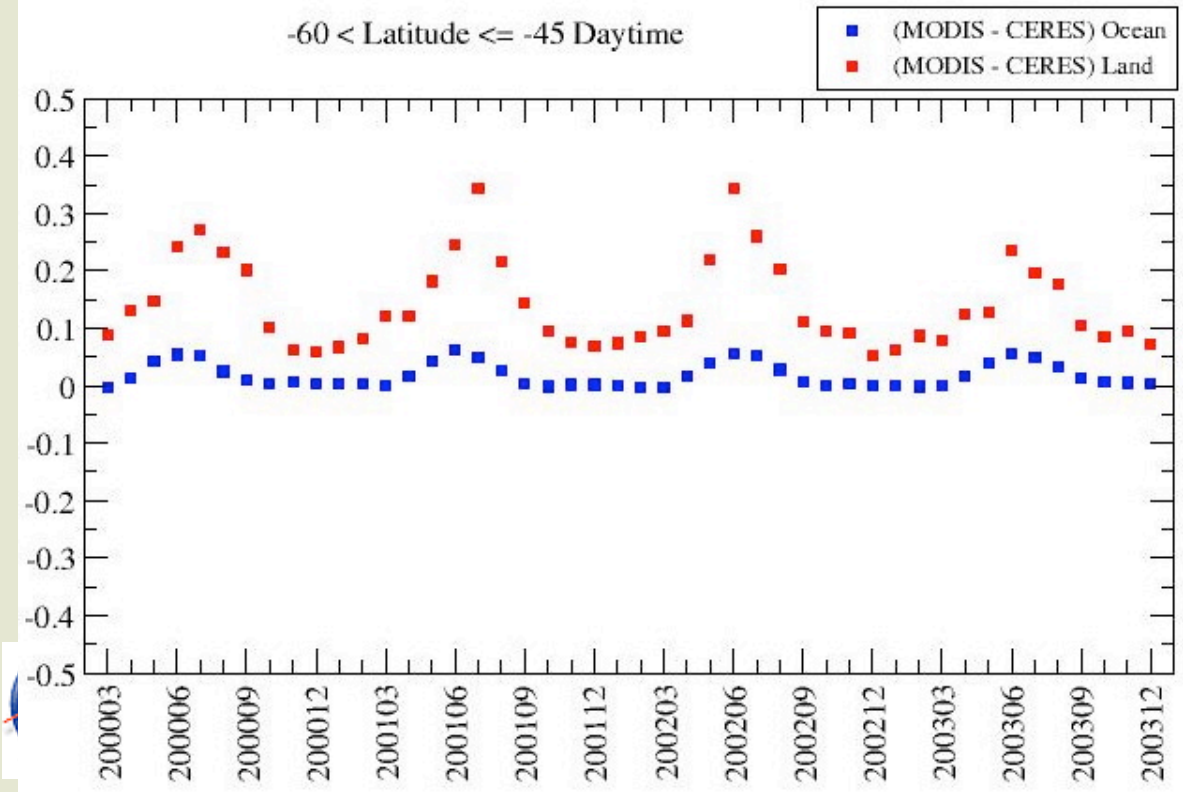
Terra, October 2003



CERES fewer clouds over ITCZ & eastern Antarctica

more clouds in Arctic & western Antarctic





Daytime comparisons

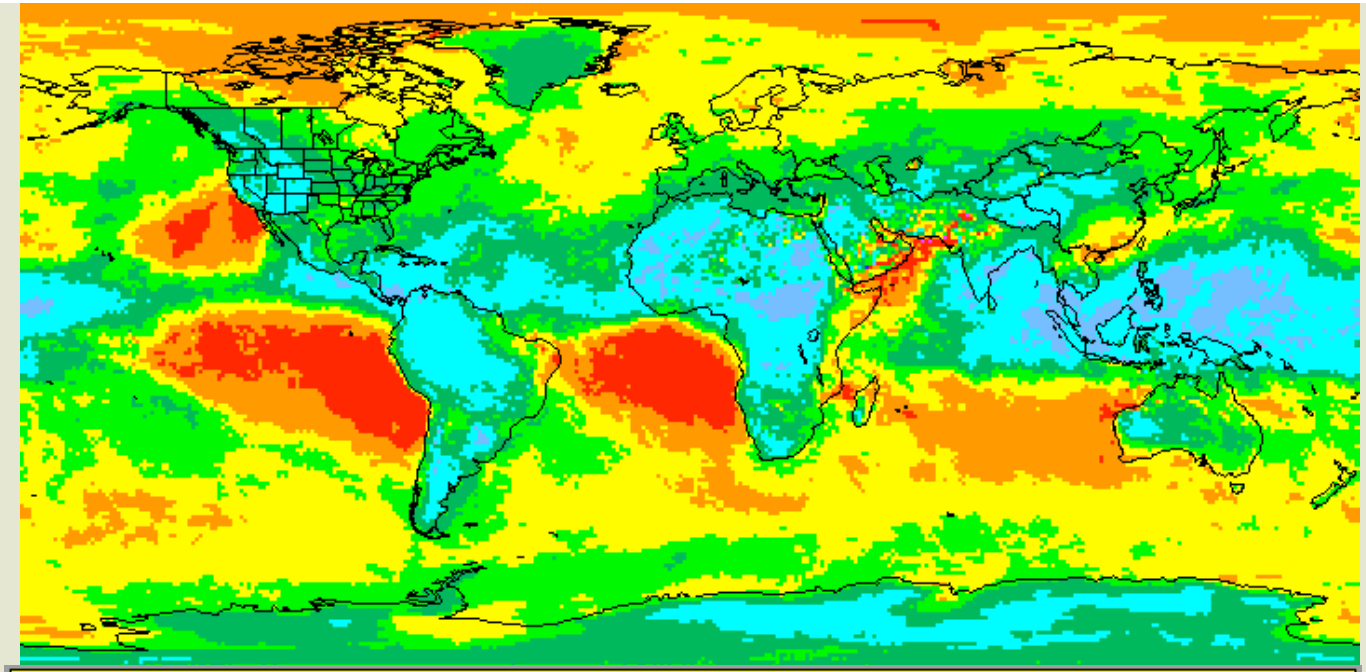
MODIS has more clouds over land and nearly the same over water in Midlatitudes

In Tropics, both land & ocean are close

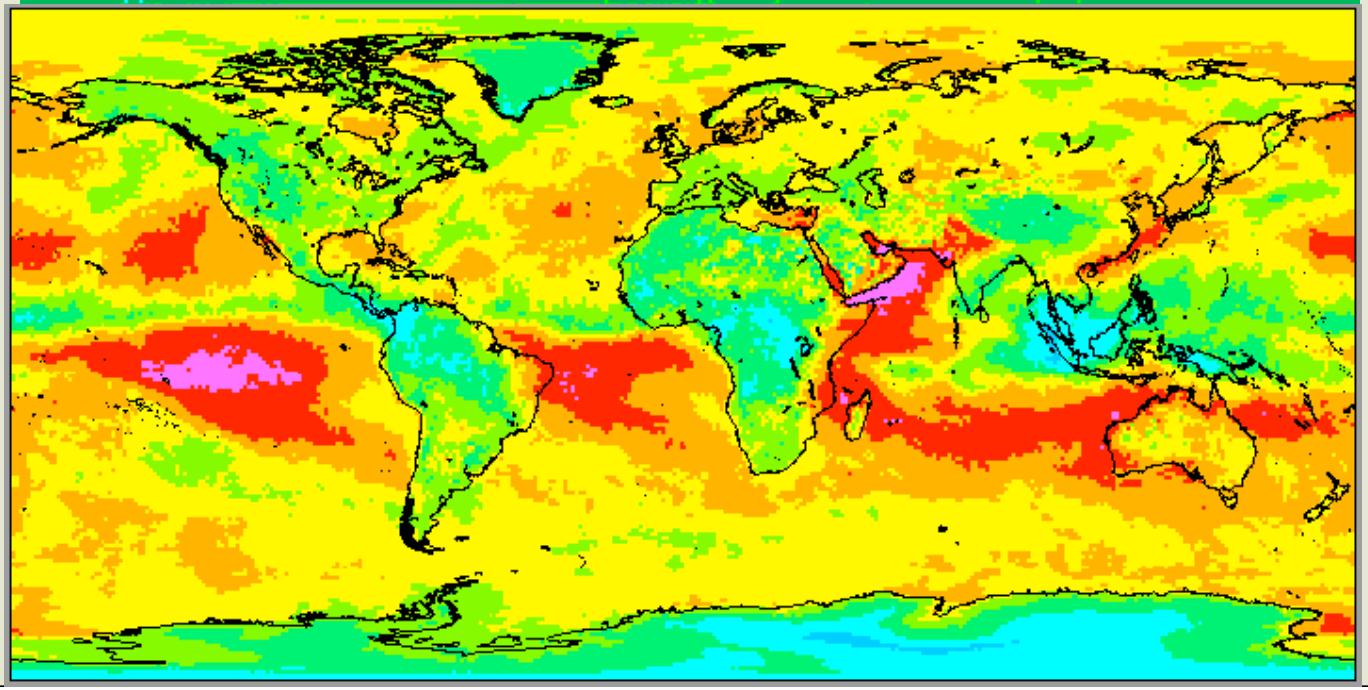
Differences very consistent year-to year with distinct seasonal cycles

TOTAL CLOUD TOP PRESSURE, *Terra*, October 2003

CERES Ed2



MOD08
MODIS Team



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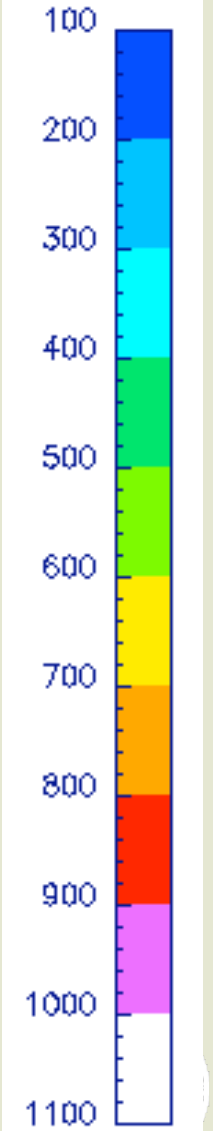
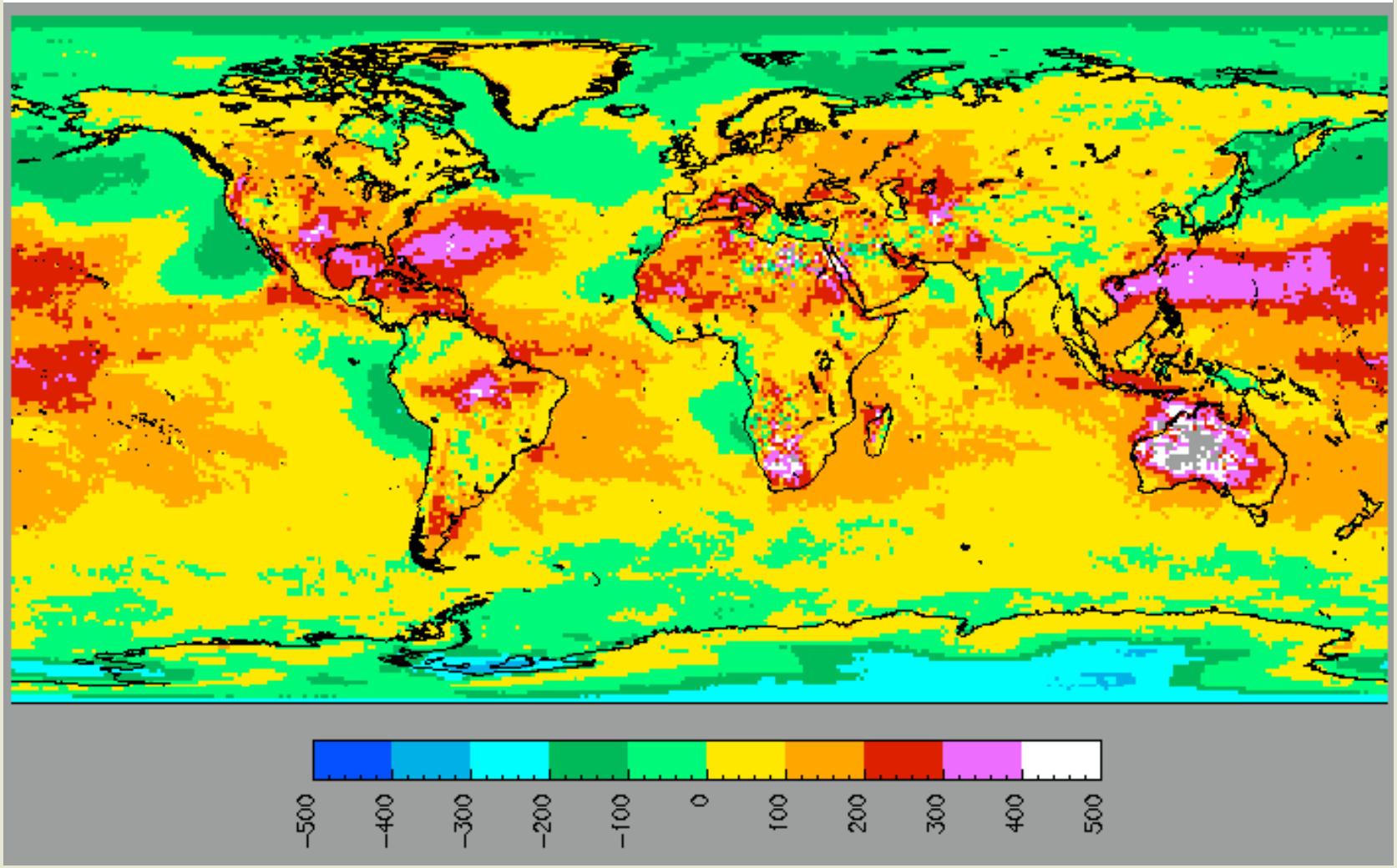


CLOUD-TOP PRESSURE DIFFERENCE, MOD08 - CERES

Terra, October 2003

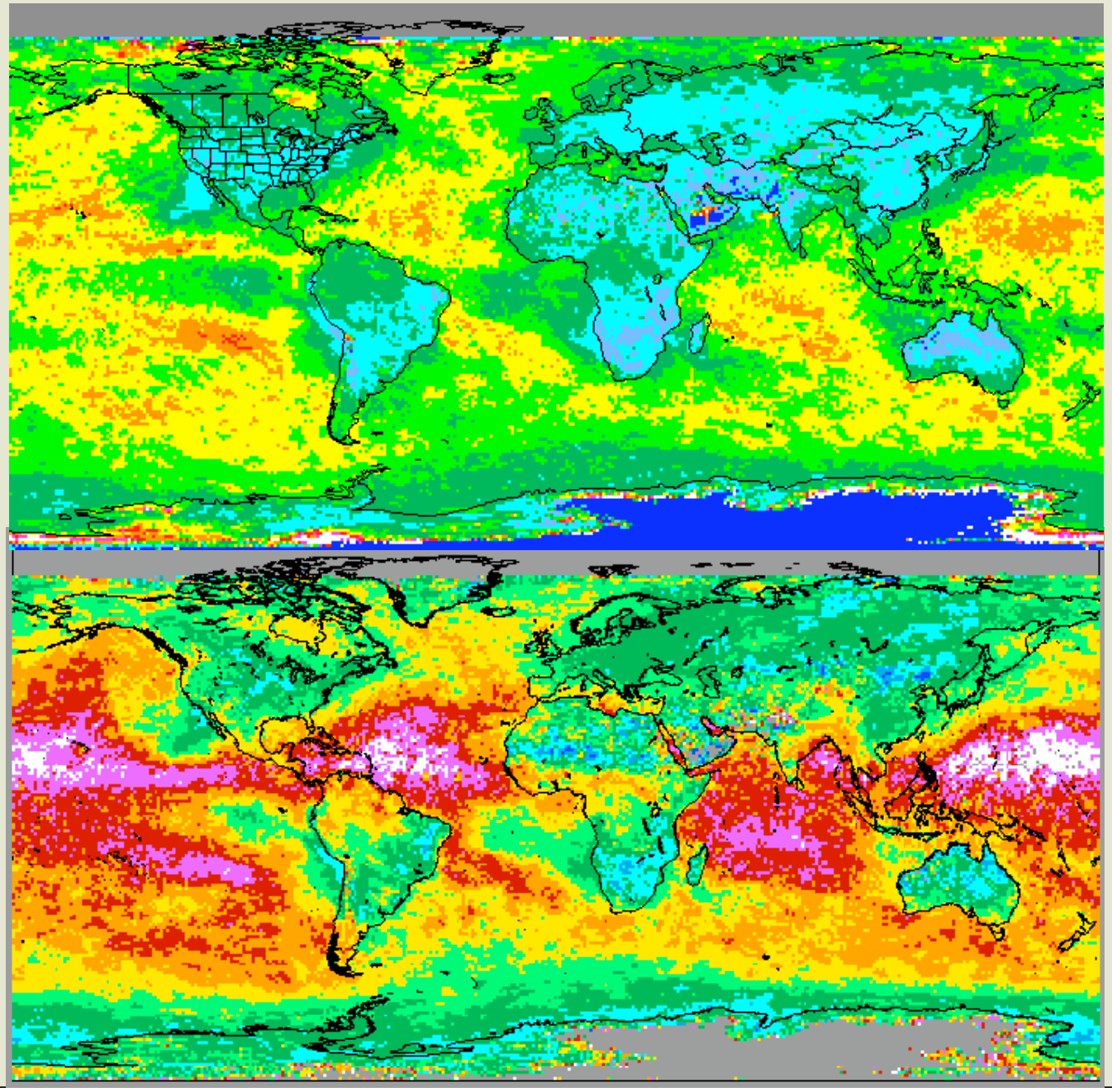


CERES lower over ocean subsidence regions; higher over deserts

WATER DROPLET EFFECTIVE RADIUS, *Terra*, October 2003

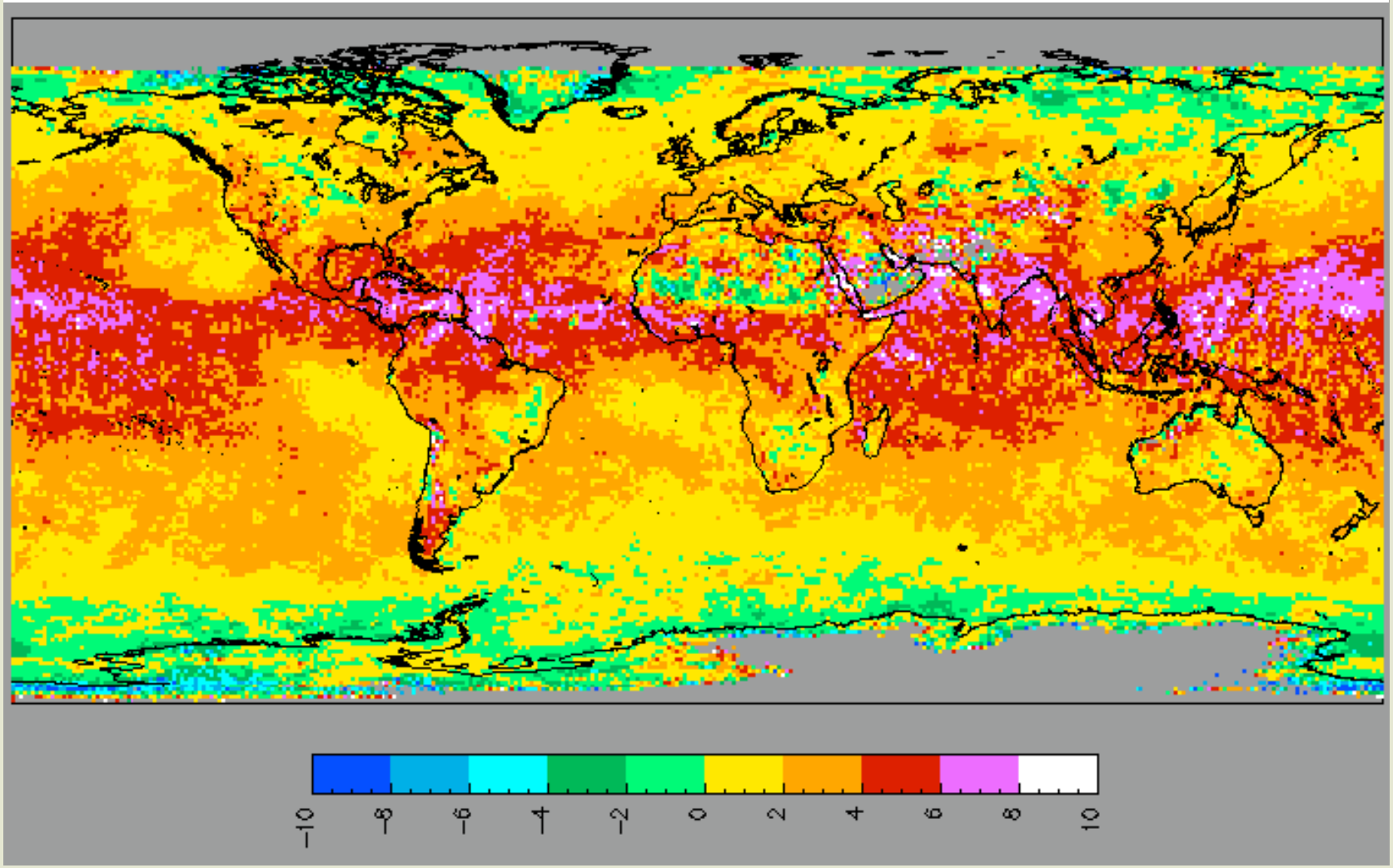
CERES Ed2

MOD08
MODIS Team



EFFECTIVE RADIUS DIFFERENCE, MOD08 - CERES

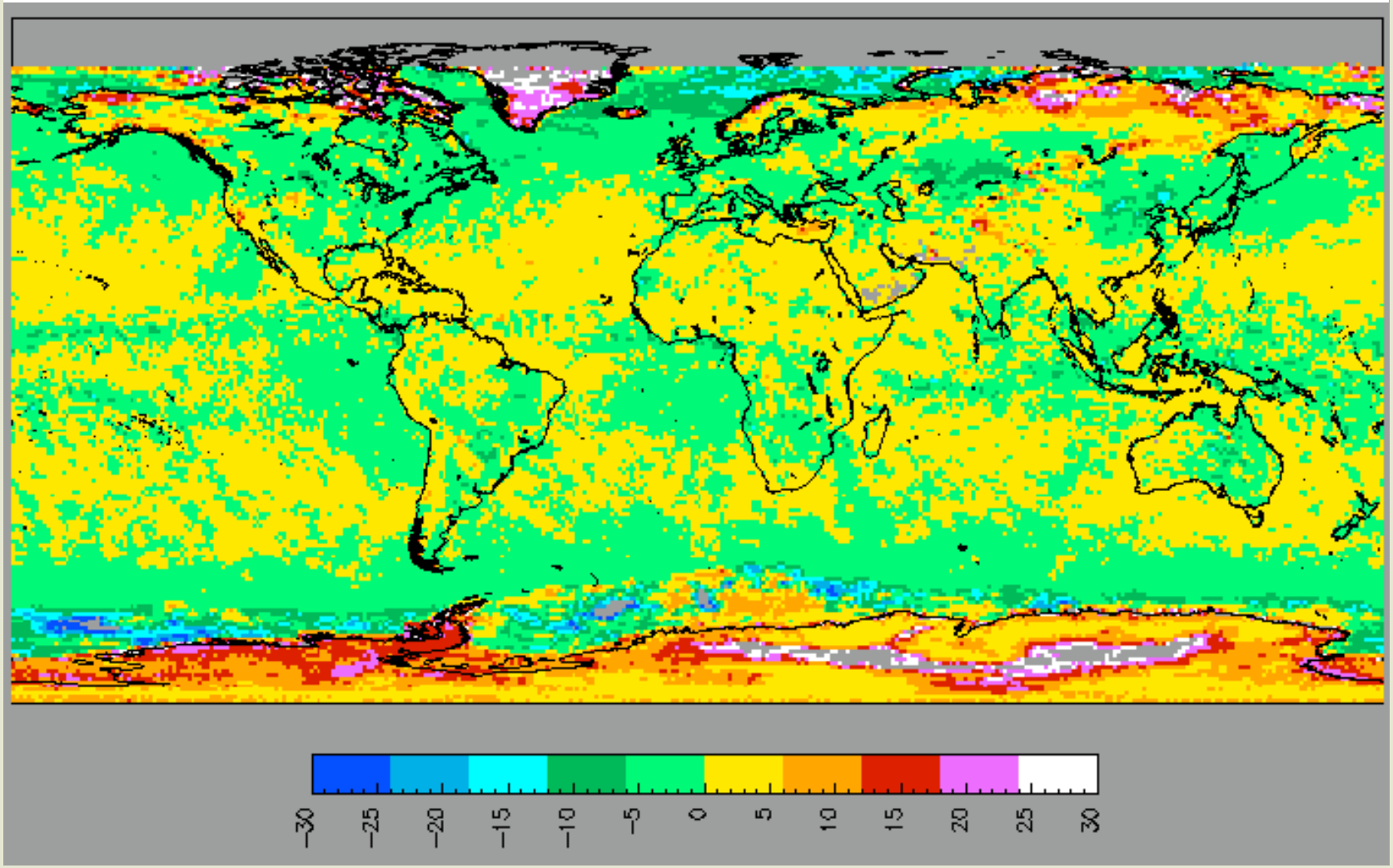
Terra, October 2003



MOD08 > CERES in most cases; differences > Aqua-Terra

TOTAL OPTICAL DEPTH DIFFERENCE, MOD08 - CERES

Terra, October 2003

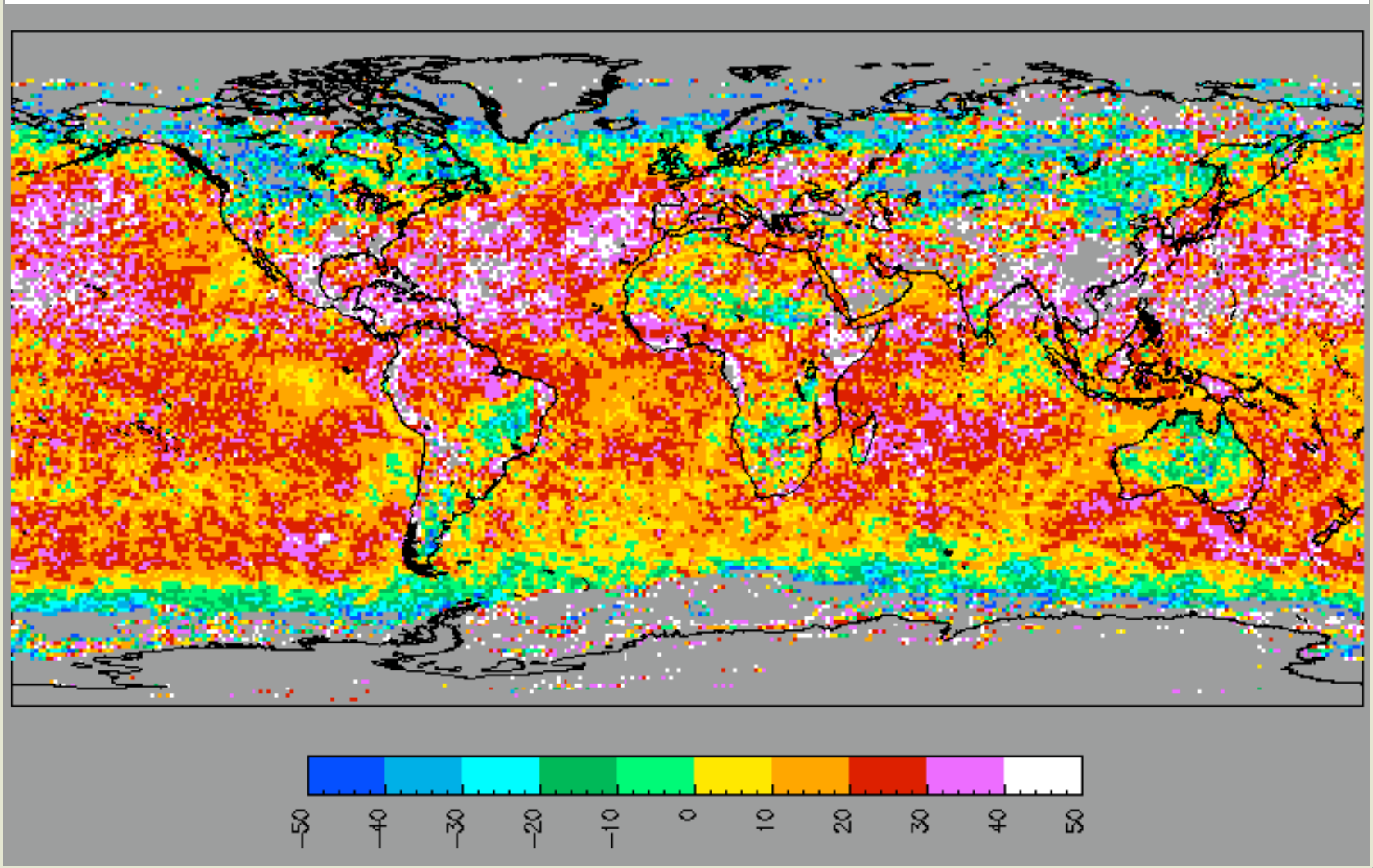


Differences large only in polar regions

- different retrieval methods over snow

LWP DIFFERENCE, MOD08 - CERES

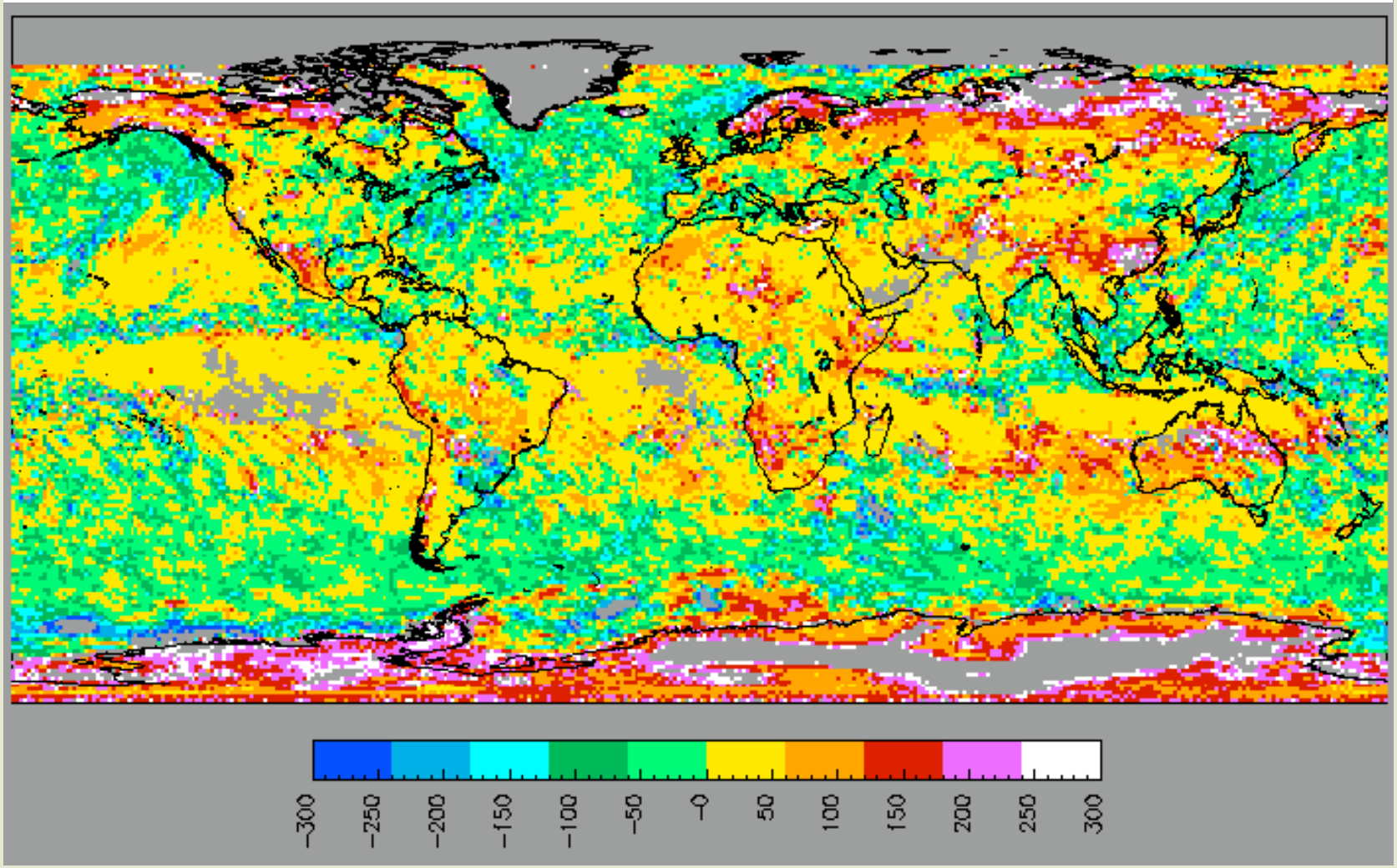
Terra, October 2003



MOD08 ~25 gm^{-2} greater on average

IWP DIFFERENCE, MOD08 - CERES

Terra, October 2003



MOD08 ~50 gm^{-2} greater on average over land, = over ocean, polar values differ significantly

SUMMARY OF MOD08-CERES COMPARISON

- **Every parameter differs**
  - *nighttime cloud amounts, polar tau, & droplet radius largest disagreements*
  - *non-polar optical depths => best agreement*
- **Differences vary with latitude and surface type**
  - *follow consistent seasonal cycles, greatest over land*
- **No apparent long term trend in the differences**
- **CERES validation efforts => most parameters quite reasonable**
  - not aware of MODIS validation assessment
  - polar region still most uncertain
  - CERES thin cirrus heights too low, yet mean heights > MOD08
  - CERES missing some thin cirrus, yet to be quantified, tau < 0.3
  - angular dependency (3-D structure, phase functions)

FUTURE

- **publish results**
- **multilayer cloud detection & interpretation**
  - combined microwave / VISST over ocean
  - secondary processing using info on BTD(11-12), τ, D_e/r_e

    => improved IWP assessment
- **improvement of nighttime/twilight everywhere including poles**
  - revise thresholds,include VIS in twilight, include 8.5 μm
  - improve surface emissivities
- **continued validation**
  - more continuous assessment at ARM sites
  - CALIPSO cloud height/amt global comparison
  - additional multiangle studies including MSG & GOES
  - in situ icing / microphysics field programs
- **better aerosol/cloud discrimination**
  - additional multispectral (MODIS) data used to detect dust

REFERENCES

List of references and pdfs given on the following web page.

http://www-pm.larc.nasa.gov/ceres/ceres-ref.html

Only imagery and summaries are available for CERES at the Cloud Working Web Page

http://lposun.larc.nasa.gov/~cwg/

Digital data avaialble at the LaRC DAAC

http://eosweb.larc.nasa.gov/HPDOCS/